7. Land Use, Land-Use Change, and Forestry

This chapter provides an assessment of the net greenhouse gas flux[1] resulting from the uses and changes in land types and forests in the United States. IPCC *Good Practice Guidance for Land Use, Land-Use Change, and Forestry* (IPCC 2003) recommends reporting fluxes according to changes within and conversions between certain land-use types, termed forest land, cropland, grassland, and settlements (as well as wetlands). The greenhouse gas flux from *Forest Land Remaining Forest Land* is reported using estimates of changes in forest carbon (C) stocks, non-carbon dioxide (CO_2) emissions from forest fires, and the application of synthetic fertilizers to forest soils. The greenhouse gas flux reported in this chapter from agricultural lands (i.e., cropland and grassland) includes changes in organic C stocks in mineral and organic soils due to land use and management, and emissions of CO_2 due to the application of crushed limestone and dolomite to managed land (i.e., soil liming). Fluxes are reported for four agricultural land use/land-use change categories: *Cropland Remaining Cropland*, *Land Converted to Cropland*, *Grassland Remaining Grassland*, and *Land Converted to Grassland*. Fluxes resulting from *Settlements Remaining Settlements* include those from urban trees and soil fertilization. Landfilled yard trimmings and food scraps are accounted for separately under *Other*.

The flux estimates in this chapter, with the exception of CO_2 fluxes from wood products, urban trees, and liming, are based on activity data collected at multiple-year intervals, which are in the form of forest, land-use, and municipal solid waste surveys. Carbon dioxide fluxes from forest C stocks (except the wood product components) and from agricultural soils (except the liming component) are calculated on an average annual basis from data collected in intervals ranging from 1 to 10 years. The resulting annual averages are applied to years between surveys. Calculations of non-CO_2 emissions from forest fires are based on forest CO_2 flux data. Agricultural mineral and organic soil C flux calculations are based primarily on national surveys, so these results are largely constant over multi-year intervals, with large discontinuities between intervals. For the landfilled yard trimmings and food scraps source, periodic solid waste survey data were interpolated so that annual storage estimates could be derived. In addition, because the most recent national forest, land-use, and municipal solid waste surveys were completed prior to 2005, the estimates of CO_2 flux from forests, agricultural soils, and landfilled yard trimmings and food scraps are based in part on extrapolation. Carbon dioxide flux from urban trees is based on neither annual data nor periodic survey data, but instead on data collected over the period 1990 through 1999. This flux has been applied to the entire time series, and periodic U.S. census data on changes in urban area have been used to develop annual estimates of CO_2 flux.

Land use, land-use change, and forestry activities in 2005 resulted in a net C sequestration of 828.4 Tg CO_2 Eq. (225.9 Tg C) (Table 7-1 and Table 7-2). This represents an offset of approximately 16 percent of total U.S. CO_2 emissions. Total land use, land-use change, and forestry net C sequestration[2] increased by approximately 16 percent between 1990 and 2005. This increase was primarily due to an increase in the rate of net C accumulation in forest C stocks. Net C accumulation in *Settlements Remaining Settlements*, *Land Converted to Grassland*, and *Cropland Remaining Cropland* increased, while net C accumulation in landfilled yard trimmings and food scraps slowed over this period. The *Grassland Remaining Grassland* land-use category resulted in net C emissions in 1990 and 1991, became a net C sink from 1992 to 1994, and then remained a fairly constant emission source. Emissions from *Land Converted to Cropland* declined between 1990 and 2005.

Table 7-1: Net CO_2 Flux from Land Use, Land-Use Change, and Forestry (Tg CO_2 Eq.)

Land-Use Category	1990		1995		2000	2001	2002	2003	2004	2005
Forest Land Remaining Forest Land	**(598.5)**		**(717.5)**		**(638.7)**	**(645.7)**	**(688.1)**	**(687.0)**	**(697.3)**	**(698.7)**

[1] The term "flux" is used here to encompass both emissions of greenhouse gases to the atmosphere, and removal of C from the atmosphere. Removal of C from the atmosphere is also referred to as "carbon sequestration."

[2] Carbon sequestration estimates are net figures. The C stock in a given pool fluctuates due to both gains and losses. When losses exceed gains, the C stock decreases, and the pool acts as a source. When gains exceed losses, the C stock increases, and the pool act as a sink. This is also referred to as net C sequestration.

Changes in Forest C Stocks[1]	(598.5)	(717.5)	(638.7)	(645.7)	(688.1)	(687.0)	(697.3)	(698.7)
Cropland Remaining Cropland	**(28.1)**	**(37.4)**	**(36.5)**	**(38.0)**	**(37.8)**	**(38.3)**	**(39.4)**	**(39.4)**
Changes in Agricultural Soil C Stocks and Liming Emissions[2]	(28.1)	(37.4)	(36.5)	(38.0)	(37.8)	(38.3)	(39.4)	(39.4)
Land Converted to Cropland	**8.7**	**7.2**	**7.2**	**7.2**	**7.2**	**7.2**	**7.2**	**7.2**
Changes in Agricultural Soil C Stocks[3]	8.7	7.2	7.2	7.2	7.2	7.2	7.2	7.2
Grassland Remaining Grassland	**0.1**	**16.4**	**16.3**	**16.2**	**16.2**	**16.2**	**16.1**	**16.1**
Changes in Agricultural Soil C Stocks[4]	0.1	16.4	16.3	16.2	16.2	16.2	16.1	16.1
Land Converted to Grassland	**(14.6)**	**(16.3)**	**(16.3)**	**(16.3)**	**(16.3)**	**(16.3)**	**(16.3)**	**(16.3)**
Changes in Agricultural Soil C Stocks[5]	(14.6)	(16.3)	(16.3)	(16.3)	(16.3)	(16.3)	(16.3)	(16.3)
Settlements Remaining Settlements[6]	**(57.5)**	**(67.8)**	**(78.2)**	**(80.2)**	**(82.3)**	**(84.4)**	**(86.4)**	**(88.5)**
Urban Trees	(57.5)	(67.8)	(78.2)	(80.2)	(82.3)	(84.4)	(86.4)	(88.5)
Other	**(23.0)**	**(13.0)**	**(8.5)**	**(8.6)**	**(8.9)**	**(9.0)**	**(8.9)**	**(8.8)**
Landfilled Yard Trimmings and Food Scraps	(23.0)	(13.0)	(8.5)	(8.6)	(8.9)	(9.0)	(8.9)	(8.8)
Total	**(712.9)**	**(828.5)**	**(754.7)**	**(765.5)**	**(809.9)**	**(811.6)**	**(824.9)**	**(828.4)**

Note: Parentheses indicate net sequestration. Totals may not sum due to independent rounding.
[1] Estimates include C stock changes on both *Forest Land Remaining Forest Land*, and *Land Converted to Forest Land*.
[2] Estimates include C stock changes in mineral soils and organic soils on *Cropland Remaining Cropland*, C stock changes in organic soils on *Land Converted to Cropland*, and liming emissions from all managed land.
[3] Estimates includes C stock changes in mineral soils only; organic soil C stock changes and liming emissions for this land use/land-use change category are reported under *Cropland Remaining Cropland*.
[4] Estimates include C stock changes in mineral soils and organic soils on *Grassland Remaining Grassland*, and C stock changes in organic soils on *Land Converted to Grassland*. Liming emissions for this land use/land-use change category are reported under *Cropland Remaining Cropland*.
[5] Estimates include C stock changes in mineral soils only; organic soil C stock changes and liming emissions for this land use/land-use change category are reported under *Grassland Remaining Grassland* and *Cropland Remaining Cropland*, respectively.
[6] Estimates include C stock changes on both *Settlements Remaining Settlements*, and *Land Converted to Settlements*. Liming emissions for this land use/land-use change category are reported under *Cropland Remaining Cropland*.

Table 7-2: Net CO_2 Flux from Land Use, Land-Use Change, and Forestry (Tg C)

Land-Use Category	1990	1995	2000	2001	2002	2003	2004	2005
Forest Land Remaining Forest Land	**(163.2)**	**(195.7)**	**(174.2)**	**(176.1)**	**(187.7)**	**(187.4)**	**(190.2)**	**(190.6)**
Changes in Forest C Stocks[1]	(163.2)	(195.7)	(174.2)	(176.1)	(187.7)	(187.4)	(190.2)	(190.6)
Cropland Remaining Cropland	**(7.7)**	**(10.2)**	**(10.0)**	**(10.4)**	**(10.3)**	**(10.4)**	**(10.7)**	**(10.7)**
Changes in Agricultural Soil C Stocks and Liming Emissions[2]	(7.7)	(10.2)	(10.0)	(10.4)	(10.3)	(10.4)	(10.7)	(10.7)
Land Converted to Cropland	**2.4**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**
Changes in Agricultural Soil C Stocks[3]	2.4	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Grassland Remaining Grassland	**0.0**	**4.5**	**4.4**	**4.4**	**4.4**	**4.4**	**4.4**	**4.4**
Changes in Agricultural Soil C Stocks[4]	0.0	4.5	4.4	4.4	4.4	4.4	4.4	4.4
Land Converted to Grassland	**(4.0)**	**(4.5)**	**(4.5)**	**(4.5)**	**(4.5)**	**(4.5)**	**(4.5)**	**(4.5)**
Changes in Agricultural Soil C Stocks[5]	(4.0)	(4.5)	(4.5)	(4.5)	(4.5)	(4.5)	(4.5)	(4.5)
Settlements Remaining Settlements[6]	**(15.7)**	**(18.5)**	**(21.3)**	**(21.9)**	**(22.4)**	**(23.0)**	**(23.6)**	**(24.1)**
Urban Trees	(15.7)	(18.5)	(21.3)	(21.9)	(22.4)	(23.0)	(23.6)	(24.1)
Other	**(6.3)**	**(3.5)**	**(2.3)**	**(2.3)**	**(2.4)**	**(2.5)**	**(2.4)**	**(2.4)**
Landfilled Yard Trimmings and Food Scraps	(6.3)	(3.5)	(2.3)	(2.3)	(2.4)	(2.5)	(2.4)	(2.4)
Total	**(194.4)**	**(225.9)**	**(205.8)**	**(208.8)**	**(220.9)**	**(221.3)**	**(225.0)**	**(225.9)**

Note: 1 Tg C = 1 teragram C = 1 million metric tons C. Parentheses indicate net sequestration. Totals may not sum due to independent rounding.
[1] Estimates include C stock changes on both *Forest Land Remaining Forest Land*, and *Land Converted to Forest Land*.
[2] Estimates include C stock changes in mineral soils and organic soils on *Cropland Remaining Cropland*, C stock changes in organic soils on *Land Converted to Cropland*, and liming emissions from all managed land.
[3] Estimates includes C stock changes in mineral soils only; organic soil C stock changes and liming emissions for this land use/land-use change category are reported under *Cropland Remaining Cropland*.

[4] Estimates include C stock changes in mineral soils and organic soils on *Grassland Remaining Grassland*, and C stock changes in organic soils on *Land Converted to Grassland*. Liming emissions for this land use/land-use change category are reported under *Cropland Remaining Cropland*.
[5] Estimates include C stock changes in mineral soils only; organic soil C stock changes and liming emissions for this land use/land-use change category are reported under *Grassland Remaining Grassland* and *Cropland Remaining Cropland*, respectively.
[6] Estimates include C stock changes on both *Settlements Remaining Settlements*, and *Land Converted to Settlements*. Liming emissions for this land use/land-use change category are reported under *Cropland Remaining Cropland*.

Non-CO_2 emissions from Land Use, Land-Use Change, and Forestry are shown in Table 7-3 and Table 7-4. The application of synthetic fertilizers to forest and settlement soils in 2005 resulted in direct N_2O emissions of 6.2 Tg CO_2 Eq. (20 Gg N_2O). Direct N_2O emissions from fertilizer application increased by approximately 19 percent between 1990 and 2005. Non-CO_2 emissions from forest fires in 2005 resulted in CH_4 emissions of 11.6 Tg CO_2 Eq. (551 Gg), and in N_2O emissions of 1.2 Tg CO_2 Eq. (4 Gg).

Table 7-3: Non-CO_2 Emissions from Land Use, Land-Use Change, and Forestry (Tg CO_2 Eq.)

Land-Use Category	1990	1995	2000	2001	2002	2003	2004	2005
Forest Land Remaining Forest Land	**7.8**	**4.5**	**15.7**	**6.9**	**11.8**	**9.2**	**8.0**	**13.1**
CH_4 Emissions from Forest Fires	7.1	4.0	14.0	6.0	10.4	8.1	6.9	11.6
N_2O Emissions from Forest Fires	0.7	0.4	1.4	0.6	1.1	0.8	0.7	1.2
N_2O Emissions from Soils[1]	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Settlements Remaining Settlements	**5.1**	**5.5**	**5.6**	**5.5**	**5.6**	**5.8**	**6.0**	**5.8**
N_2O Emissions from Soils[2]	5.1	5.5	5.6	5.5	5.6	5.8	6.0	5.8
Total	**13.0**	**10.1**	**21.3**	**12.4**	**17.4**	**15.0**	**13.9**	**18.9**

Note: These estimates include direct emissions only. Indirect N_2O emissions are reported in the Agriculture chapter. Totals may not sum due to independent rounding.
[1] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land*, and *Land Converted to Forest Land*, but not from land-use conversion.
[2] Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements*, and *Land Converted to Settlements*, but not from land-use conversion.

Table 7-4: Non-CO_2 Emissions from Land Use, Land-Use Change, and Forestry (Gg)

Land-Use Category	1990	1995	2000	2001	2002	2003	2004	2005
Forest Land Remaining Forest Land								
CH_4 Emissions from Forest Fires	337	189	667	285	494	384	330	551
N_2O Emissions from Forest Fires	2	1	5	2	3	3	2	4
N_2O Emissions from Soils[1]	0	1	1	1	1	1	1	1
Settlements Remaining Settlements								
N_2O Emissions from Soils[2]	17	18	18	18	18	19	19	19

Note: These estimates include direct emissions only. Indirect N_2O emissions are reported in the Agriculture chapter. Totals may not sum due to independent rounding.
[1] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land*, and *Land Converted to Forest Land*, but not from land-use conversion.
[2] Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements*, and *Land Converted to Settlements*, but not from land-use conversion.

7.1. Forest Land Remaining Forest Land

Changes in Forest Carbon Stocks (IPCC Source Category 5A1)

For estimating C stocks or stock change (flux), C in forest ecosystems can be divided into the following five storage pools (IPCC 2003):

- Aboveground biomass, which includes all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage. This category includes live understory.
- Belowground biomass, which includes all living biomass of coarse living roots greater than 2 mm

diameter.

- Dead wood, which includes all non-living woody biomass either standing, lying on the ground (but not including litter), or in the soil.
- Litter, which includes the litter, fumic, and humic layers, and all non-living biomass with a diameter less than 7.5 cm at transect intersection, lying on the ground.
- Soil organic carbon (SOC), including all organic material in soil to a depth of 1 meter but excluding the coarse roots of the aboveground pools.

In addition, there are two harvested wood pools also necessary for estimating C flux, which are:

- Harvested wood products in use.
- Harvested wood products in solid waste disposal sites (SWDS).

C is continuously cycled among these storage pools and between forest ecosystems and the atmosphere as a result of biological processes in forests (e.g., photosynthesis, respiration, growth, mortality, decomposition, and disturbances such as fires or pest outbreaks) and anthropogenic activities (e.g., harvesting, thinning, clearing, and replanting). As trees photosynthesize and grow, C is removed from the atmosphere and stored in living tree biomass. As trees age, they continue to accumulate C until they reach maturity, at which point they store a relatively constant amount of C. As trees die and otherwise deposit litter and debris on the forest floor, C is released to the atmosphere or transferred to the soil by organisms that facilitate decomposition.

The net change in forest C is not equivalent to the net flux between forests and the atmosphere because timber harvests do not cause an immediate flux of C to the atmosphere. Instead, harvesting transfers C to a "product pool." Once in a product pool, the C is emitted over time as CO_2 when the wood product combusts or decays. The rate of emission varies considerably among different product pools. For example, if timber is harvested to produce energy, combustion releases C immediately. Conversely, if timber is harvested and used as lumber in a house, it may be many decades or even centuries before the lumber decays and C is released to the atmosphere. If wood products are disposed of in SWDS, the C contained in the wood may be released many years or decades later, or may be stored almost permanently in the SWDS.

This section quantifies the net changes in C stocks in the five forest C pools and two harvested wood pools. The net change in stocks for each pool is estimated, and then the changes in stocks are summed over all pools to estimate total net flux. Thus, the focus on C implies that all C-based greenhouse gases are included, and the focus on stock change suggests that specific ecosystem fluxes do not need to be separately itemized in this report. Disturbances from forest fires and pest outbreaks are implicitly included in the net changes. For instance, an inventory conducted after fire counts only trees left. The change between inventories thus accounts for the C changes due to fires; however, it may not be possible to attribute the changes to the disturbance specifically. The IPCC (2003) recommends reporting C stocks according to several land-use types and conversions, specifically *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*. Currently, consistent datasets are not available for the entire United States to allow results to be partitioned in this way. Instead, net changes in all forest-related land, including non-forest land converted to forest and forests converted to non-forest are reported here.

Forest C storage pools, and the flows between them via emissions, sequestration, and transfers, are shown in Figure 7-1. In the figure, boxes represent forest C storage pools and arrows represent flows between storage pools or between storage pools and the atmosphere. Note that the boxes are not identical to the storage pools identified in this chapter. The storage pools identified in this chapter have been altered in this graphic to better illustrate the processes that result in transfers of C from one pool to another, and emissions to the atmosphere as well as uptake from the atmosphere.

Figure 7-1: Forest Sector Carbon Pools and Flows

Approximately 33 percent (303 million hectares) of the U.S. land area is forested, of which approximately 250 million hectares are located in the conterminous 48 states. An additional 52 million hectares are located in Alaska and Hawaii, though this inventory does not currently account for these stocks and fluxes due to data limitations. Hawaii and U.S. territories have relatively small areas of forest land and will probably not affect the overall C budget to a great degree. Alaska has over 50 million hectares of forest land, however, and more efforts will be made to account for this area in the future (see Planned Improvements for more details). Agroforestry systems are also not currently accounted for in the U.S. Inventory, since they are not explicitly inventoried by either of the two primary national natural resource inventory programs: the Forest Inventory and Analysis (FIA) program of the U.S. Department of Agriculture (USDA) Forest Service and the National Resources Inventory (NRI) of the USDA Natural Resources Conservation Service (Perry et al. 2005).

Seventy-nine percent of the 250 million hectares are classified as timberland, meaning they meet minimum levels of productivity and are available for timber harvest. Historically, the timberlands in the conterminous 48 states have been more frequently or intensively surveyed than other forest lands. Of the remaining 51 million hectares, 16 million hectares are reserved forest lands (withdrawn by law from management for production of wood products) and 35 million hectares are lower productivity forest lands (Smith et al. 2004b). From the early 1970s to the early 1980s, forest land declined by approximately 2.4 million hectares. During the 1980s and 1990s, forest area increased by about 3.7 million hectares. These net changes in forest area represent average annual fluctuations of only about 0.1 percent. Given the low rate of change in U.S. forest land area, the major influences on the current net C flux from forest land are management activities and the ongoing impacts of previous land-use changes. These activities affect the net flux of C by altering the amount of C stored in forest ecosystems. For example, intensified management of forests can increase both the rate of growth and the eventual biomass density of the forest, thereby increasing the uptake of C.[3] Harvesting forests removes much of the aboveground C, but trees can grow on this area again and sequester C. The reversion of cropland to forest land increases C storage in biomass, forest floor, and soils. The net effects of forest management and the effects of land-use change involving forest land are captured in the estimates of C stocks and fluxes presented in this chapter.

In the United States, improved forest management practices, the regeneration of previously cleared forest areas, as well as timber harvesting and use have resulted in net uptake (i.e., net sequestration) of C each year from 1990 through 2005. Due to improvements in U.S. agricultural productivity, the rate of forest clearing for crop cultivation and pasture slowed in the late 19th century, and by 1920, this practice had all but ceased. As farming expanded in the Midwest and West, large areas of previously cultivated land in the East were taken out of crop production, primarily between 1920 and 1950, and were allowed to revert to forests or were actively reforested. The impacts of these land-use changes still affect C fluxes from forests in the East. In addition, C fluxes from eastern forests have been affected by a trend toward managed growth on private land. Collectively, these changes have nearly doubled the biomass density in eastern forests since the early 1950s. More recently, the 1970s and 1980s saw a resurgence of federally-sponsored forest management programs (e.g., the Forestry Incentive Program) and soil conservation programs (e.g., the Conservation Reserve Program), which have focused on tree planting, improving timber management activities, combating soil erosion, and converting marginal cropland to forests. In addition to forest regeneration and management, forest harvests have also affected net C fluxes. Because most of the timber harvested from U.S. forests is used in wood products, and many discarded wood products are disposed of in SWDS rather than by incineration, significant quantities of C in harvested wood are transferred to long-term storage pools rather than being released rapidly to the atmosphere (Skog and Nicholson 1998, Skog in preparation). The size of these long-term C storage pools has increased during the last century.

Changes in C stocks in U.S. forests and harvested wood were estimated to account for net sequestration of 698.7 Tg CO_2 Eq. (190.6 Tg C) in 2005 (Table 7-5, Table 7-6, and Figure 7-2). In addition to the net accumulation of C in harvested wood pools, sequestration is a reflection of net forest growth and increasing forest area over this period, though the increase in forest sequestration is due more to an increasing C density per area than to the increase in area of forest land. Forest land in the conterminous United States was approximately 246, 250, and 251 million

[3] The term "biomass density" refers to the mass of vegetation per unit area. It is usually measured on a dry-weight basis. Dry biomass is 50 percent carbon by weight.

hectares for 1987, 1997, and 2002, respectively, which amounts to only a 2 percent increase over the period (Smith et al. 2004b). Continuous, regular annual surveys are not available over the period for each state; therefore, estimates for non-survey years were derived by interpolation between known data points. Survey years vary from state to state. National estimates are a composite of individual state surveys. Total sequestration increased by 17 percent between 1990 and 2005 (see *Recalculations Discussion*). Estimated sequestration in the aboveground biomass C pool had the greatest effect on total change. This was primarily due to an increase in the rate of net C accumulation as density, or the rate of change in tonnes of C per hectare per year, approximately a 21 percent increase over the 1990 through 2005 time series. This increase is particularly evident for the aboveground and belowground tree biomass pools, for which rate of C accumulation increased by about 37 percent.

Table 7-5. Net Annual Changes in C Stocks (Tg CO_2/yr) in Forest and Harvested Wood Pools

Carbon Pool	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Forest	**(466.5)**	**(602.0)**	**(529.4)**	**(555.5)**	**(595.3)**	**(595.3)**	**(595.3)**	**(595.3)**
Aboveground Biomass	(251.8)	(331.0)	(347.1)	(360.4)	(376.4)	(376.4)	(376.4)	(376.4)
Belowground Biomass	(63.9)	(69.8)	(73.9)	(76.4)	(79.5)	(79.5)	(79.5)	(79.5)
Dead Wood	(36.7)	(60.9)	(48.2)	(50.0)	(52.4)	(52.4)	(52.4)	(52.4)
Litter	(65.6)	(49.5)	(35.8)	(47.1)	(52.2)	(52.2)	(52.2)	(52.2)
Soil Organic Carbon	(48.5)	(90.8)	(24.5)	(21.6)	(34.8)	(34.8)	(34.8)	(34.8)
Harvested Wood	**(132.0)**	**(115.5)**	**(109.3)**	**(90.2)**	**(92.8)**	**(91.7)**	**(101.9)**	**(103.4)**
Products in use	(63.1)	(53.5)	(46.2)	(31.2)	(34.1)	(33.4)	(43.3)	(44.4)
SWDS	(68.9)	(62.0)	(63.1)	(59.0)	(58.7)	(58.3)	(58.7)	(59.0)
Total Net Flux	**(598.5)**	**(717.5)**	**(638.7)**	**(645.7)**	**(688.1)**	**(687.0)**	**(697.3)**	**(698.7)**

Note: Forest C stocks do not include forest stocks in Alaska, Hawaii, or U.S. territories, or trees on non-forest land (e.g., urban trees, agroforestry systems). Parentheses indicate net C sequestration (i.e., a net removal of C from the atmosphere). Total net flux is an estimate of the actual net flux between the total forest C pool and the atmosphere. Forest area estimates are based on interpolation and extrapolation of inventory data as described in the text and in Annex 3.12. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding.

Table 7-6. Net Annual Changes in C Stocks (Tg C/yr) in Forest and Harvested Wood Pools

Carbon Pool	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Forest	**(127.2)**	**(164.2)**	**(144.4)**	**(151.5)**	**(162.4)**	**(162.4)**	**(162.4)**	**(162.4)**
Aboveground Biomass	(68.7)	(90.3)	(94.7)	(98.3)	(102.7)	(102.7)	(102.7)	(102.7)
Belowground Biomass	(17.4)	(19.0)	(20.1)	(20.8)	(21.7)	(21.7)	(21.7)	(21.7)
Dead Wood	(10.0)	(16.6)	(13.1)	(13.6)	(14.3)	(14.3)	(14.3)	(14.3)
Litter	(17.9)	(13.5)	(9.8)	(12.9)	(14.2)	(14.2)	(14.2)	(14.2)
Soil Organic Carbon	(13.2)	(24.8)	(6.7)	(5.9)	(9.5)	(9.5)	(9.5)	(9.5)
Harvested Wood	**(36.0)**	**(31.5)**	**(29.8)**	**(24.6)**	**(25.3)**	**(25.0)**	**(27.8)**	**(28.2)**
Products in use	(17.2)	(14.6)	(12.6)	(8.5)	(9.3)	(9.1)	(11.8)	(12.1)
SWDS	(18.8)	(16.9)	(17.2)	(16.1)	(16.0)	(15.9)	(16.0)	(16.1)
Total Net Flux	**(163.2)**	**(195.7)**	**(174.2)**	**(176.1)**	**(187.7)**	**(187.4)**	**(190.2)**	**(190.6)**

Note: Forest C stocks do not include forest stocks in Alaska, Hawaii, or U.S. territories, or trees on non-forest land (e.g., urban trees, agroforestry systems). Parentheses indicate net C sequestration (i.e., a net removal of C from the atmosphere). Total net flux is an estimate of the actual net flux between the total forest C pool and the atmosphere. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding.

Stock estimates for forest and harvested wood C storage pools are presented in Table 7-7. Together, the aboveground live and forest soil pools account for a large proportion of total forest C stocks. C stocks in all non-soil pools increased over time. Therefore, C sequestration was greater than C emissions from forests, as discussed above. Figure 7-3 shows county-average C densities for live trees on forest land, including both above- and belowground biomass.

Table 7-7. Forest area (1000 ha) and C Stocks (Tg C) in Forest and Harvested Wood Pools

	1990	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Forest Area (1000 ha)	**242,300**	**245,946**	**250,275**	**251,110**	**251,977**	**252,879**	**253,782**	**254,684**	**255,587**

Carbon Pools (Tg C)									
Forest	**39,026**	**39,762**	**40,576**	**40,721**	**40,872**	**41,035**	**41,197**	**41,359**	**41,522**
Aboveground Biomass	14,164	14,565	15,031	15,125	15,224	15,326	15,429	15,532	15,634
Belowground Biomass	2,794	2,885	2,983	3,003	3,024	3,045	3,067	3,089	3,110
Dead Wood	2,354	2,418	2,499	2,512	2,526	2,540	2,555	2,569	2,583
Litter	4,404	4,497	4,559	4,569	4,582	4,596	4,610	4,625	4,639
Soil Organic C	15,310	15,398	15,505	15,511	15,517	15,527	15,536	15,546	15,555
Harvested Wood	**1,888**	**2,067**	**2,225**	**2,255**	**2,287**	**2,317**	**2,341**	**2,367**	**2,395**
Products in use	1,184	1,268	1,341	1,354	1,368	1,381	1,389	1,399	1,411
SWDS	704	799	884	901	919	936	952	968	984
Total C Stock	**40,914**	**41,829**	**42,801**	**42,976**	**43,159**	**43,352**	**43,538**	**43,726**	**43,917**

Note: Forest area estimates are based on interpolation and extrapolation of inventory data as described in the text and in Annex 3.12. Forest C stocks do not include forest stocks in Alaska, Hawaii, or U.S. territories, or trees on non-forest land (e.g., urban trees, agroforestry systems). Wood product stocks include exports, even if the logs are processed in other countries, and exclude imports. Forest area estimates are based on interpolation and extrapolation of inventory data as described in the text and in Annex 3.12. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding. Inventories are assumed to represent stocks as of January 1 of the inventory year. Flux is the net annual change in stock. Thus, an estimate of flux for 2005 requires estimates of C stocks for 2005 and 2006.

Figure 7-2: Estimates of Net Annual Changes in C Stocks for Major C Pools

Figure 7-3: Average C Density in the Forest Tree Pool in the Conterminous United States During 2005

[BEGIN BOX]

Box 7-1: CO_2 Emissions from Forest Fires

As stated previously, the forest inventory approach implicitly accounts for emissions due to disturbances such as forest fires, because only C remaining in the forest is estimated. Net C stock change is estimated by subtracting consecutive C stock estimates. A disturbance removes C from the forest. The inventory data on which net C stock estimates are based already reflect this C loss. Therefore, estimates of net annual changes in C stocks for U.S. forestland already account for CO_2 emissions from forest fire, but only for the lower 48 states. As detailed previously, Alaska is not yet included in national estimates of forest C stocks and fluxes, due to lack of forest inventory data at this time (see *Planned Improvements*). Wildfire data is, however, available for Alaska, so it has been included in these calculations. Because it is of interest to quantify the magnitude of CO_2 emissions from fire disturbance, these estimates are being highlighted here, using the full extent of available data. Non-CO_2 greenhouse gas emissions from forest fires are also quantified in a separate section below.

The IPCC (2003) methodology was employed to estimate CO_2 emissions from forest fires. CO_2 emissions for the lower 48 states and Alaska in 2005 were estimated to be 126.4 Tg CO_2/yr. This amount is masked in the estimates of total flux for 2005, however, by an additional 126.4 Tg CO_2/yr being sequestered (i.e., flux already accounts for the amount sequestered minus any emissions).

Table 7-8: Estimates of CO_2 (Tg/yr) emissions for the lower 48 states and Alaska[1]

Year	CO_2 emitted in the Lower 48 States (Tg/yr)	CO_2 emitted in Alaska (Tg/yr)	Total CO_2 emitted (Tg/yr)
1990	42.7	34.5	77.2
1995	42.9	0.5	43.3

2000	144.6	8.2	152.8
2001	63.0	2.4	65.3
2002	89.7	23.6	113.3
2003	81.4	6.5	87.9
2004	5.0	70.6	75.6
2005	75.9	50.5	126.4

[1] Note that these emissions have already been accounted for in the net C sequestration estimates (i.e., net flux already accounts for the amount sequestered minus any emissions).

[END BOX]

Methodology

The methodology described herein is consistent with IPCC (2003) and IPCC/UNEP/OECD/IEA (1997). Estimates of net annual C stock change, or flux, of forest ecosystems are derived from applying C estimation factors to forest inventory data and interpolating between successive inventory-based estimates of C stocks. C emissions from harvested wood are based on factors such as the allocation of wood to various primary and end-use products as well as half-life (the time at which half of amount placed in use will have been discarded from use) and expected disposition (e.g., product pool, SWDS, combustion). Different data sources are used to estimate the C stocks and stock change in forest ecosystems or harvested wood products. See Annex 3.12 for details and additional information related to the methods described below.

Forest Carbon Stocks and Fluxes

The first step in developing forest ecosystem estimates is to identify useful inventory data and resolve any inconsistencies among datasets. Forest inventory data were obtained from the USDA Forest Service, Forest Inventory and Analysis (FIA) program (Frayer and Furnival 1999, USDA Forest Service 2006a). Inventories include forest lands[4] of the conterminous United States and are organized as a number of separate datasets, each representing a complete inventory, or survey, of an individual state at a specified time. Forest C calculations are organized according to these state surveys, and the frequency of surveys varies by state. To calculate a C stock change, at least two surveys are needed in each state. Thus, the most recent surveys for each state are used as well as all additional consistent inventory data back through 1990. Because C flux is based on change between successive C stocks, consistent representation of forest land in successive inventories is necessary. In order to achieve accurate representation of forests from 1990 to the present, sometimes state-level data are subdivided or additional inventory sources are used to produce the consistent state or sub-state inventories.

The principal FIA forest inventory datasets employed are freely available for download at USDA Forest Service (2006b) as the Forest Inventory and Analysis Database (FIADB) Version 2.1. These data are identified as "snapshot" files, also identified as FISDB 2.1, and include detailed plot information, including individual-tree data. However, to achieve consistent representation (spatial and temporal), two other general sources of past FIA data are included as necessary. Firstly, older FIA plot- and tree-level data—not in the FIADB format—are used if available. Secondly, Resources Planning Act Assessment (RPA) databases, which are periodic, plot-level only, summaries of state inventories, are used mostly to provide the data at or before 1990. A detailed list of the specific inventory data used here is in Table A-188 of Annex 3.12.

[4] Forest land in the United States includes land that is at least 10 percent stocked with trees of any size. Timberland is the most productive type of forest land, which is on unreserved land and is producing or capable of producing crops of industrial wood.

Forest C stocks are estimated from inventory data by a collection of conversion factors and models referred to as FORCARB2 (Birdsey and Heath 1995, Birdsey and Heath 2001, Heath et al. 2003, Smith et al. 2004a), which have been formalized in an application referred to as the Carbon Calculation Tool (CCT), (Smith et al in preparation). The conversion factors and model coefficients are usually categorized by region and forest type, and forest C stock estimates are dependent on these particular sets of factors. Factors are applied to the data at the scale of FIA inventory plots. The results are estimates of C density (Mg per hectare) for the various forest pools. C density for live trees, standing dead trees, understory vegetation, down dead wood, forest floor, and soil organic matter are estimated. All non-soil pools except forest floor can be separated into aboveground and belowground components. The live tree and understory C pools are pooled as biomass in this inventory. Similarly, standing dead trees and down dead wood are pooled as dead wood in this inventory. Definitions of ecosystem pools and the C conversion process follow, with additional information in Annex 3.12.

Live Biomass, Dead Wood, and Litter Carbon

Live tree C pools include aboveground and belowground (coarse root) biomass of live trees with diameter at diameter breast height (d.b.h.) of at least 2.54 cm at 1.37 m above the forest floor. Separate estimates are made for full-tree and aboveground-only biomass in order to estimate the belowground component. If inventory plots include data on individual trees, tree C is based on Jenkins et al. (2003) and is a function of species and diameter. Some inventory data do not provide measurements of individual trees; tree C in these plots is estimated from plot-level volume of merchantable wood, or growing-stock volume, of live trees, which is calculated from updates of Smith et al. (2003). Some inventory data, particularly some of the older datasets, may not include sufficient information to calculate tree C because of incomplete or missing tree or volume data; C estimates for these plots are based on averages from similar, but more complete, inventory data.

Understory vegetation is a minor component of biomass, which is defined as all biomass of undergrowth plants in a forest, including woody shrubs and trees less than 2.54 cm d.b.h. In this inventory, it is assumed that 10 percent of total understory C mass is belowground. Estimates of C density are based on information in Birdsey (1996).

The two components of dead wood—standing dead trees and down dead wood—are estimated separately. The standing dead tree C pools include aboveground and belowground (coarse root) mass and include trees of at least 2.54 cm d.b.h. Down dead wood is defined as pieces of dead wood greater than 7.5 cm diameter, at transect intersection, that are not attached to live or standing dead trees. Down dead wood includes stumps and roots of harvested trees. Ratios of down dead wood to live tree are used to estimate this quantity. Litter C is the pool of organic C (also known as duff, humus, and fine woody debris) above the mineral soil and includes woody fragments with diameters of up to 7.5 cm. Estimates are based on equations of Smith and Heath (2002).

Forest Soil C

Soil organic carbon (SOC) includes all organic material in soil to a depth of 1 meter but excludes the coarse roots of the biomass or dead wood pools. Estimates of SOC are based on the national STATSGO spatial database (USDA 1991), and the general approach described by Amichev and Galbraith (2004). Links to FIA inventory data were developed with the assistance of the USDA Forest Service FIA Geospatial Service Center by overlaying FIA forest inventory plots on the soil C map. Thus, SOC is defined by region and forest type group.

C stocks and fluxes for *Forest Land Remaining Forest Land* are reported in pools following IPCC (2003). Total forest C stock and flux estimates start with the plot-level calculations described above. The separate C densities are summed and multiplied by the appropriate expansion factors to obtain a C stock estimate for the plot. In turn, these are summed to state or sub-state total C stocks. Annualized estimates of C stocks are based on interpolating or extrapolating as necessary to assign a C stock to each year. For example, the C stock of Alabama for 2005 is an extrapolation of the two most recent inventory datasets for that particular state, which are from 1999 and 2003. Flux, or net annual stock change, is simply the difference between two successive years with the appropriate sign convention so that net increases in ecosystem C are identified as negative flux. This methodological detail accounts for the constant estimates of flux from the second most recent inventory to the present (see 2002 through 2005 on Table 7-5 as an example).

Harvested Wood Carbon

Estimates of the harvested wood product (HWP) contribution to forest C sinks and emissions (hereafter called "HWP Contribution") are based on methods described in Skog (in preparation) using the WOODCARB II model. These are based on the methods suggested in IPCC (2006) for estimating HWP carbon. The United States uses the production accounting approach to report HWP Contribution. This means that C in exported wood is estimated as if it remains in the United States, and C in imported wood is not included in Inventory estimates. Though the production approach is used in this inventory, estimates resulting from use of the two alternative approaches, the stock change and atmospheric flow approaches, are also presented for comparison (see Annex 3.12). Annual estimates of change in four HWP summary quantities are calculated by tracking the additions to and removals from the pool of products held in end uses (i.e., products in use such as housing or publications, and the pool of products held in solid waste disposal sites (SWDS)). These four categories of annual change of C in wood and paper products are 1) all products in use in the United States; 2) all products in SWDS in the United States; 3) products in use in the United States and other countries where the wood came from trees harvested in the United States; and 4) products in SWDS in the United States and other countries where the wood came from trees harvested in the United States.

Solidwood products added to pools include lumber and panels. End-use categories for solidwood include single and multifamily housing, alteration and repair of housing, and other end-uses. There is one product category and one end-use category for paper. Additions to and removals from pools are tracked beginning in 1900, with the exception that additions of softwood lumber to housing begins in 1800. Solidwood and paper product production and trade data are from USDA Forest Service and other sources (Hair and Ulrich 1963; Hair 1958; USDC Bureau of Census; 1976; Ulrich, 1985, 1989; Steer 1948; AF&PA 2006a 2006b; Howard 2003 & forthcoming). Estimates for disposal of products reflect the change over time in the fraction of products discarded to SWDS (as opposed to burning or recycling) and the fraction of SWDS that are in sanitary landfills versus dumps.

Summary categories 3 and 4 (above) are used to estimate HWP Contribution under the production accounting approach. A key assumption for estimating these variables is that products exported from the United States and held in pools in other countries have the same half lives for products in use, the same percentage of discarded products going to SWDS, and the same decay rates in SWDS as they would in the United States.

Uncertainty

The forest survey data that underlie the forest C estimates are based on a statistical sample designed to represent the wide variety of growth conditions present over large territories. The USDA Forest Service inventories are designed to be accurate within 3 percent at the 67 percent confidence level (one standard error) per 405,000 ha (1 million acres) of timberland (USDA Forest Service 2006c). For larger areas, the uncertainty in area is concomitantly smaller, and precision at plot levels is larger. An analysis of uncertainty in growing stock volume data for timber producing land in the Southeast by Phillips et al. (2000) found that nearly all of the uncertainty in their analysis was due to sampling rather than the regression equations used to estimate volume from tree height and diameter. The quantitative uncertainty analysis summarized here (and in Table 7-9) primarily focuses on uncertainties associated with the estimates of specific C stocks at the plot level and does not address error in tree diameters or volumes.

Estimates for stand-level C pools are derived from extrapolations of site-specific studies to all forest land, because survey data on these pools are not generally available. Such extrapolation introduces uncertainty because available studies may not adequately represent regional or national averages. Uncertainty may also arise due to: (1) modeling errors (e.g., relying on coefficients or relationships that are not well known); and (2) errors in converting estimates from one reporting unit to another (Birdsey and Heath 1995). An important source of uncertainty is that there is little consensus from available data sets on the effect of land-use change and forest management activities (such as harvest) on soil C stocks. For example, while Johnson and Curtis (2001) found little or no net change in soil C following harvest, on average, across a number of studies, many of the individual studies did exhibit differences. Heath and Smith (2000) noted that the experimental design in a number of soil studies limited their usefulness for determining effects of harvesting on soil C. Because soil C stocks are large, estimates need to be very precise, since even small relative changes in soil C sum to large differences when integrated over large areas. The soil C stock and stock change estimates presented here are based on the assumption that soil C density for each broad forest type group stays constant over time. The state of information and modeling are improving in this regard (Woodbury et al. 2006); the effects of land use and of changes in land use and forest management will be better accounted for in future estimates of soil C.

Uncertainty in estimates about the HWP Contribution is based on Monte Carlo simulation of the production approach. The uncertainty analysis is based on Skog et al. (2004). However, the uncertainty analysis simulation has been revised in conjunction with overall revisions in the HWP model (Skog in preparation). The analysis includes an evaluation of the effect of uncertainty in 13 sources including production and trade data, factors to convert products to quantities of C, rates at which wood and paper are discarded, and rates and limits for decay of wood and paper in SWDS.

The 2005 flux estimate for forest C stocks is estimated to be between -513.1 and -889.5 Tg CO_2 Eq. at a 95 percent confidence level. This includes a range of -410.5 to -785.2 Tg CO_2 Eq. in forest ecosystems and -78.9 to -130.2 Tg CO_2 Eq. for HWP. The relatively smaller range of uncertainty, in terms of percentage, for the total relative to the two separate parts in because the total is based on summing the two independent uncertain parts, as discussed above.

Table 7-9: Tier 2 Quantitative Uncertainty Estimates for Net CO_2 Flux from Forest Land Remaining Forest Land: Changes in Forest C Stocks (Tg CO_2 Eq. and Percent)

Source	**Gas**	**2005 Flux Estimate (Tg CO_2 Eq.)**	**Uncertainty Range Relative to Flux Estimate[a] (Tg CO_2 Eq.)**		**(%)**	
			Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Forest Ecosystem	CO_2	(595.3)	(785.2)	(410.5)	-32%	+31%
Harvested Wood Products	CO_2	(103.4)	(130.2)	(78.9)	-26%	+24%
Total Forest	**CO_2**	**(698.7)**	**(889.5)**	**(513.1)**	**-27%**	**+27%**

Note: Parentheses indicate negative values or net sequestration.

[a] Range of flux estimates predicted by Monte Carlo stochastic simulation for a 95 percent confidence interval.

QA/QC and Verification

As discussed above, the FIA program has conducted consistent forest surveys based on extensive statistically-based sampling of most of the forest land in the conterminous United States, dating back to 1952. The main purpose of the FIA program has been to estimate areas, volume of growing stock, and timber products output and utilization factors. The FIA program includes numerous quality assurance and quality control (QA/QC) procedures, including calibration among field crews, duplicate surveys of some plots, and systematic checking of recorded data. Because of the statistically-based sampling, the large number of survey plots, and the quality of the data, the survey databases developed by the FIA program form a strong foundation for C stock estimates. Field sampling protocols, summary data, and detailed inventory databases are archived and are publicly available on the Internet (USDA Forest Service 2006b).

Many key calculations for estimating current forest C stocks based on FIA data are based on coefficients from the FORCARB2 model (see additional discussion in the Methodology section above and in Annex 3.12). The model has been used for many years to produce national assessments of forest C stocks and stock changes. General quality control procedures were used in performing calculations to estimate C stocks based on survey data. For example, the derived C datasets, which include inventory variables such as areas and volumes, were compared with standard inventory summaries such as Resources Planning Act (RPA) Forest Resource Tables or selected population estimates generated from the FIA Database (FIADB), which are available at an FIA Internet site (USDA Forest Service 2006b). Agreement between the C datasets and the original inventories is important to verify accuracy of the data used. Finally, C stock estimates were compared with previous inventory report estimates to ensure that any differences could be explained by either new data or revised calculation methods (see the “Recalculations” discussion below).

Estimates of the HWP variables and the HWP Contribution under the production accounting approach use data from U.S. Census and USDA Forest Service surveys of production and trade. Factors to convert wood and paper from original units to C units are based on estimates by industry and Forest Service published sources. The WOODCARB II model uses estimation methods suggested by the IPCC (2006). Estimates of annual C change in solidwood and paper products in use were verified by two independent criteria. The first criteria is that the WOODCARB II model estimate of C in houses standing in 2001 needs to match an independent estimate of C in housing based on U.S. Census and USDA Forest Service survey data. Meeting the first criteria resulted in an estimated half life of about 80 years for single family housing built in the 1920s, which is confirmed by other U.S. Census data on housing. The second criteria is that the WOODCARB II model estimate of wood and paper being discarded to SWDS needs to match EPA estimates of discards each year over the period 1990 to 2000. These criteria help reduce uncertainty in estimates of annual change in C in products in use in the United States and to a lesser degree reduces uncertainty in estimates of annual change in C in products made from wood harvested in the United States.

Recalculations Discussion

The overall scheme for developing annualized estimates of forest ecosystem C stocks based on the individual state surveys and the C conversion factors used are similar to that presented in the previous inventory (EPA 2006). The principal change from the previous year's methods involves the increased use of sub-state classification of the survey data as indicated in Table A-188 in Annex 3.12, which details the survey data used for the current inventory. For the current inventory, the emphasis was on improving consistency between successive surveys or portions of surveys when sub-state portions of inventory data provided better continuity. The FIADB "snapshot" datasets were the primary source of FIA inventory data. Secondary sources included the plot and tree data from older, pre-FIADB, inventories and the plot-level RPA datasets. By improving the consistency of these datasets, substantial revisions were made to previous estimates, which primarily affected early years in the calculations. The new calculations of forest C stocks in 1990 decreased the estimate of C sequestration by 23 percent (174.9 Tg CO2 Eq.), while increasing C sequestration estimates for forest C stocks in 2004 by 9 percent (60.1 Tg CO2 Eq.).

The change in stock and flux estimates for the period since 1990, as compared to the estimates presented in the previous inventory, is based on the cumulative effects of 1) additional inventory data, and 2) how the state or sub-state inventories are classified. State-level inventory data changed more dramatically for some particular states as compared to others. As an example, stock and flux estimates for the state of California are based on the FIA datasets specified in Table A-188 in Annex 3.12. In past inventories (for example, EPA 2006), chaparral ecosystems were included in forest inventory data and, therefore, forest C stock estimates. However, much of this ecological community type fails to meet the definition of forestland. Current FIA forest inventory data does not include non-forest land of this ecological community. In order to maintain consistency across the time series, non-forest chaparral estimates had to be removed from California's total stock estimates in earlier inventories. This caused a dramatic decrease in forest C stock estimates at the early part of the time series for the state of California compared to those California estimates used for the previous inventory submission.

The estimate of HWP contribution under the production account approach has been revised. Estimates of 5 HWP variables have been added, which allow estimates using alternate accounting approaches. The basic method used to estimate the HWP variables has not changed—tracking additions to and removals from pools—but more detailed product and trade data are used and discard and decay parameters have been revised. With use of more detailed production and trade data and modification in half lives for solidwood and paper product in use (to meet calibration criteria), the estimates of C additions to product in use (under the production approach) varies differently from year to year. Average annual total additions due to HWP from the period 1990 through 2004 (111 Tg CO_2 Eq.) is about 47 percent less than the previous estimate of 209 Tg CO_2 Eq. The estimate of total C in products in use in 2004 has increased from 1344 Tg to 1389 Tg. Changes have been greater for estimates of C additions to SWDS. Estimates of the fractions of discarded wood going to landfills and dumps were revised using data from EPA (2006 and prior years), Melosi (1981, 2000) and other sources. Estimates of the fraction of wood and paper not subject to decay in landfills were revised, based on Freed and Mintz (2003), using data from studies by Eleazer et al. (1997) and Barlaz (1998). The estimated fraction of C in wood subject to decay in landfills was revised from 3 percent to 23 percent, while the estimated fraction of C in paper subject to decay in landfills increased from 26 percent to 56 percent. Those fractions of wood and paper not subject to decay, therefore, decreased. Previous estimates of wood and paper subject to decay in landfills had been based on Micales and Skog (1997). Estimates of the rates of decay in landfills and dumps were also updated to 29 years and 14.5 years, respectively, using values from IPCC (2006). These half-lives are the midpoints of the estimated ranges of decay for wood and paper in temperate regions. The estimate of total C additions in SWDS over the period 1990 through 2004 decreased from 630 Tg to 256 Tg. Overall, the estimate of C additions under the production accounting approach over the period 1990 to 2004 has decreased from 857 Tg to 455 Tg, or 47 percent.

Another change in the current inventory is the inclusion of estimates of C emissions caused by fire disturbance. Although these emissions are implicitly included in total forest C flux estimates, expert and public reviews of previous inventories indicated an interest in the magnitude of this flux. An estimate of C emissions was, therefore, calculated and included in Box 7-1 in the current inventory. C emissions caused by fire disturbance are still implicitly included as part of the overall forest C flux estimate, and, thus, not treated as a separate estimate in the current inventory.

Non-CO_2 emissions from forest fires is a new source included in the current inventory. CH_4 and N_2O emissions resulting from forest fires were not previously calculated, but these estimates are now included in their own subsection of *Forest Land Remaining Forest Land*.

Planned Improvements

The ongoing annual surveys by the FIA Program will improve precision of forest C estimates as new state surveys become available (Gillespie 1999). The annual surveys will eventually include all states. Therefore, inventory-based estimates of net annual flux for Alaska will become available, starting with the more productive forest in the southeastern portion of the state. Forest inventory data is limited in Alaska and, in the past, a net C change of zero was assumed. Alaska has over 50 million hectares of forest land, however, and could have a significant effect on estimates of total C emissions and sinks. A review of the scientific literature indicates Alaskan forests could change U.S. national forest C flux estimates by –5 to 10 percent (not including harvested wood). In addition, the more intensive sampling of down dead wood, litter, and soil organic C on some of the permanent FIA plots will substantially improve resolution of C pools at the plot level for all U.S. forest land.

As more information becomes available about historical land use, the ongoing effects of changes in land use and forest management will be better accounted for in estimates of soil C (Birdsey and Lewis 2003, Woodbury et al. 2006). Currently, soil C estimates are based on the assumption that soil C density depends only on broad forest type group, not on land-use history. However, many forests in the Eastern United States are re-growing on abandoned agricultural land. During such regrowth, soil and forest floor C stocks often increase substantially over many years or even decades, especially on highly eroded agricultural land. In addition, with deforestation, soil C stocks often decrease over many years. A new methodology is being developed to account for these changes in soil C over time. This methodology includes estimates of area changes among land uses (especially forest and agriculture), estimates of the rate of soil C stock gain with afforestation, and estimates of the rate of soil C stock loss with deforestation over time. This topic is important because soil C stocks are large, and soil C flux estimates contribute substantially to total forest C flux.

Similarly, agroforestry practices, such as windbreaks or riparian forest buffers along waterways, are not currently accounted for in the inventory. In order to properly account for the C stocks and fluxes associated with agroforestry, research will be needed that provides the basis and tools for including these plantings into a nation-wide inventory, as well as the means for entity-level reporting.

An additional planned improvement is to develop a consistent representation of the U.S. managed land base. Currently, the forest C and the agricultural soil C inventories are the two major analyses addressing land-use and management impacts on C stocks. The forest inventory relies on the activity data from the FIA Program to estimate anthropogenic impacts on forest land, while the agricultural soil C inventory relies on the USDA National Resources Inventory (NRI). Recent research has revealed that the classification of forest land is not consistent between the FIA and NRI, leading to some double-counting and gaps in the current forest C and agricultural soil C inventories (e.g., some areas classified as forest land in the FIA are considered rangeland in the NRI). Consequently, the land bases are in the process of being compared between the inventories to determine where overlap or gaps occur, and then ensure that the inventories are revised to have a consistent and complete accounting of land-use and management impacts across all managed land in the United States.

Non-CO_2 Emissions From Forest Fires

Emissions of non-CO_2 gases from forest fires were estimated using the default IPCC (2003) methodology. Emissions from this source in 2005 were estimated to be 11.6 Tg CO_2 Eq.of CH_4 and 1.2 Tg CO_2 Eq. of N_2O, as shown in Table 7-10 and Table 7-11. The non-CO_2 estimates of forest fire emissions account for both the lower 48 states and Alaska, while the national inventory estimates of forest C stocks and fluxes currently include only the conterminous states.

Table 7-10: Estimated Non-CO_2 Emissions from Forest Fires (Tg CO_2 Eq.) for U.S. forests[1]

Gas	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
CH_4	7.1	4.0	14.0	6.0	10.4	8.1	6.9	11.6
N_2O	0.7	0.4	1.4	0.6	1.1	0.8	0.7	1.2
Total	**7.8**	**4.4**	**15.4**	**6.6**	**11.4**	**8.9**	**7.6**	**12.8**

[1] Calculated based on C emission estimates in *Changes in Forest Carbon Stocks* and default factors in IPCC (2003).

Table 7-11: Estimated Non-CO_2 Emissions from Forest Fires (Gg Gas) for U.S. forests[1]

Gas	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
CH_4	337	189	667	285	494	384	330	551
N_2O	2	1	5	2	3	3	2	4

[1] Calculated based on C emission estimates in *Changes in Forest Carbon Stocks* and default factors in IPCC (2003).

Methodology

The IPCC (2003) Tier 2 default methodology was used to calculate non-CO_2 emissions from forest fires. Estimates for CH_4 emissions were calculated by multiplying the total estimated C emitted (see Table 7-12) from forest burned by gas-specific emissions ratios and conversion factors. N_2O emissions were calculated in the same manner, but were also multiplied by a N-C ratio of 0.01 as recommended by IPCC (2003). The equations used were:

$$CH_4 \text{ Emissions} = (\text{C released}) \times (\text{emission ratio}) \times 16/12$$

$$N_2O \text{ Emissions} = (\text{C released}) \times (\text{N/C ratio}) \times (\text{emission ratio}) \times 44/28$$

Estimates for C emitted from forest fires, presented in Table 7-12 below, are the same estimates used to generate estimates of CO_2 emissions from forest fires, presented earlier in Box 7-1. See Table A-197 and explanation in Annex 3.12 for more details on the methodology used to estimate C emitted from forest fires.

Table 7-12: Estimated Carbon Released from Forest Fires for U.S. Forests

Year	**C Emitted (Tg/yr)**
1990	21.1
1995	11.8
2000	41.7
2001	17.8
2002	30.9
2003	24.0
2004	20.6
2005	34.5

Uncertainty

Non-CO_2 gases emitted from forest fires depend on several variables, including forest area and average C density for forest land in both Alaska and the lower 48 states, emission ratios, and combustion factor values (proportion of biomass consumed by fire). To quantify the uncertainties for emissions from forest fires, a Monte Carlo (Tier 2) uncertainty analysis was performed using the information provided above. The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 7-14.

Table 7-13: Tier 2 Quantitative Uncertainty Estimates of Non-CO_2 Emissions from Forest Fires in *Forest Land Remaining Forest Land* (Tg CO_2 Eq. and Percent)

Source	**Gas**	**2005 Emission Estimate (Tg CO_2 Eq.)**	**Uncertainty Range Relative to Emission Estimate (Tg CO_2 Eq.)**		**(%)**	
			Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Non-CO_2 Emissions from Forest Fires	CH_4	11.6	3.2	21.5	-71%	92%
	N_2O	1.2	0.3	2.2	-70%	93%

Direct N_2O Fluxes from Forest Soils (IPCC Source Category 5A1)

Of the synthetic N fertilizers applied to soils in the United States, no more than one percent is applied to forest soils. Application rates are similar to those occurring on cropped soils, but in any given year, only a small proportion of total forested land receives N fertilizer. This is because forests are typically fertilized only twice during their approximately 40-year growth cycle (once at planting and once approximately 20 years later). Thus, although the rate of N fertilizer application for the area of forests that receives N fertilizer in any given year is relatively high, average annual applications, inferred by dividing all forest land that may undergo N fertilization at some point during its growing cycle by the amount of N fertilizer added to these forests in a given year, is quite low. Nitrous oxide emissions from forest soils are estimated to have increased by a multiple of 5.5 from 1990 to 2005. The trend toward increasing N_2O emissions is a result of an increase in the area of N fertilized pine plantations in the southeastern United States. Total forest soil N_2O emissions are summarized in Table 7-14.

Table 7-14. N_2O Fluxes from Soils in *Forest Land Remaining Forest Land* (Tg CO_2 Eq. and Gg)

Year	**Tg CO_2 Eq.**	**Gg**
1990	0.1	<1
1995	0.2	1
2000	0.3	1
2001	0.3	1
2002	0.3	1
2003	0.3	1
2004	0.3	1
2005	0.3	1

Note: These estimates include direct N_2O emissions from N fertilizer additions only. Indirect N_2O emissions from fertilizer additions are reported in the Agriculture chapter. These estimates include emissions from both *Forest Land Remaining Forest Land* and from *Land Converted to Forest Land*.

Methodology

The IPCC Tier 1 approach was used to estimate N_2O from soils within *Forest Land Remaining Forest Land*. According to U.S. Forest Service statistics for 1996 (USDA Forest Service 2001), approximately 75 percent of trees planted were for timber, and about 60 percent of national total harvested forest area are in the southeastern United States. Consequently, it was assumed that southeastern pine plantations represent the vast majority of fertilized forests in the United States. Therefore, estimates of direct N_2O emissions from fertilizer applications to forests were based on the area of pine plantations receiving fertilizer in the southeastern United States and estimated application rates (North Carolina Sate Forest Nutrition Cooperative 2002). Not accounting for fertilizer applied to non-pine plantations is justified because fertilization is routine for pine forests but rare for hardwoods (Binkley et al. 1995).

For each year, the area of pine receiving N fertilizer was multiplied by the midpoint of the reported range of N fertilization rates (150 lbs. N per acre). Data for areas of forests receiving fertilizer outside the southeastern United States were not available, so N additions to non-southeastern forests are not included here. It should be expected, however, that emissions from the small areas of fertilized forests in other regions would be insubstantial because the majority of trees planted and harvested for timber are in the southeastern United States (USDA Forest Service 2001). Area data for pine plantations receiving fertilizer in the Southeast were not available for 2002, 2003, 2004, and 2005, so data from 2001 were used for these years. The N applied to forests was multiplied by the IPCC (2006) default emission factor of 1 percent to estimate direct N_2O emissions. The volatilization and leaching/runoff fractions, calculated according to the IPCC default factors of 10 percent and 30 percent, respectively, were included with all sources of indirect emissions in the Agricultural Soil Management source category of the Agriculture chapter.

Uncertainty

The amount of N_2O emitted from forests depends not only on N inputs, but also on a large number of variables, including organic C availability, O_2 partial pressure, soil moisture content, pH, temperature, and tree planting/harvesting cycles. The effect of the combined interaction of these variables on N_2O flux is complex and highly uncertain. The IPCC default methodology used here does not incorporate any of these variables and only accounts for variations in estimated fertilizer application rates and estimated areas of forested land receiving N fertilizer. All forest soils are treated equivalently under this methodology. Furthermore, only synthetic N fertilizers are captured, so applications of organic N fertilizers are not accounted for here. However, the total quantity of organic N inputs to soils are accounted for in the Agricultural Soil Management and *Settlements Remaining Settlements* sections.

Uncertainties exist in the fertilizer application rates, the area of forested land receiving fertilizer, and the emission factors used to derive emission estimates.

To quantify the uncertainties for N_2O fluxes from forest soils, a Monte Carlo (Tier 2) uncertainty analysis was performed using the information provided above. The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 7-15. N_2O fluxes from soils were estimated to be between 0.1 and 1.1 Tg CO_2 Eq. at a 95 percent confidence level. This indicates a range of 59 percent below and 211 percent above the 2005 emission estimate of 0.3 Tg CO_2 Eq.

Table 7-15: Tier 2 Quantitative Uncertainty Estimates of N_2O Fluxes from Soils in *Forest Land Remaining Forest Land* (Tg CO_2 Eq. and Percent)

Source	**Gas**	**2005 Emission Estimate (Tg CO_2 Eq.)**	**Uncertainty Range Relative to Emission Estimate (Tg CO_2 Eq.)**		**(%)**	
			Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Forest Land Remaining Forest Land: N_2O Fluxes from Soils	N_2O	0.3	0.1	1.1	-59%	+211%

Note: This estimate includes direct N_2O emissions from N fertilizer additions to both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

Recalculations Discussion

The IPCC default emission factor of 1.25 percent for direct emissions from applied N was updated to 1 percent based on IPCC (2006). Additionally, because the direct emission factor was developed based on total N inputs, the new method has been revised to estimate direct N_2O emissions based on total N input. Previously, a portion of the N inputs were removed from the calculation of direct N_2O emissions, because it was assumed to be lost through volatilization before direct emissions occurred.

Planned Improvements

Area data for southeastern pine plantations receiving fertilizer will be updated with more recent datasets.

7.2. Land Converted to Forest Land (IPCC Source Category 5A2)

Land-use change is constantly occurring, and areas under a number of differing land-use types are converted to forest each year, just as forest land is converted to other uses. However, the magnitude of these changes is not currently known. Given the paucity of available land-use information relevant to this particular IPCC source category, it is not possible to separate CO_2 or N_2O fluxes on *Land Converted to Forest Land* from fluxes on *Forest Land Remaining Forest Land* at this time.

7.3. Cropland Remaining Cropland (IPCC Source Category 5B1)

Soils contain both organic and inorganic forms of C, but soil organic carbon (SOC) stocks are the main source or sink for atmospheric CO_2 in most soils. Changes in inorganic C stocks are typically minor. Soil organic C is the dominant organic C pool in cropland ecosystems, because biomass and dead organic matter have considerably less C and those pools are relatively ephemeral. IPCC/UNEP/OECD/IEA (1997) recommends reporting changes in soil organic C stocks due to agricultural land-use and management activities on mineral soils and organic soils. In addition, the IPCC Guidelines recommend reporting CO_2 emissions that result from liming of soils with dolomite and limestone.

Typical well-drained mineral soils contain from 1 to 6 percent organic C by weight, although some mineral soils that are saturated with water for substantial periods during the year may contain significantly more C (NRCS 1999). When mineral soils undergo conversion from their native state to agricultural uses, as much as half the SOC can be lost to the atmosphere. The rate and ultimate magnitude of C loss will depend on pre-conversion conditions, conversion method and subsequent management practices, climate, and soil type. In the tropics, 40 to 60 percent of the C loss generally occurs within the first 10 years following conversion; C stocks continue to decline in subsequent decades but at a much slower rate. In temperate regions, C loss can continue for several decades, reducing stocks by 20 to 40 percent of native C levels. Eventually, the soil can reach a new equilibrium that reflects a balance between C inputs (e.g., decayed plant matter, roots, and organic amendments such as manure and crop residues) and C loss through microbial decomposition of organic matter. However, land use, management, and other conditions may change before the new equilibrium is reached. The quantity and quality of organic matter inputs and their rate of decomposition are determined by the combined interaction of climate, soil properties, and land use. Land use and agricultural practices such as clearing, drainage, tillage, planting, grazing, crop residue management, fertilization, and flooding, can modify both organic matter inputs and decomposition, and thereby result in a net flux of C to or from the pool of soil C.

Organic soils, also referred to as histosols, include all soils with more than 12 to 20 percent organic C by weight, depending on clay content (NRCS 1999, Brady and Weil 1999). The organic layer of these soils can be very deep (i.e., several meters), forming under inundated conditions, in which minimal decomposition of plant residue occurs. When organic soils are prepared for crop production, they are drained and tilled, leading to aeration of the soil, which accelerates the rate of decomposition and CO_2 emissions. Because of the depth and richness of the organic layers, C loss from drained organic soils can continue over long periods of time. The rate of CO_2 emissions varies depending on climate and composition (i.e., decomposability) of the organic matter. Also, the use of organic soils for annual crop production leads to higher C loss rates than drainage of organic soils in grassland or forests, due to deeper drainage and more intensive management practices in cropland (Armentano and Verhoeven 1990, as cited in IPCC/UNEP/OECD/IEA 1997). C losses are estimated from drained organic soils under both grassland and cropland management in this inventory.

The last category of the IPCC methodology addresses emissions from lime additions (in the form of crushed limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) to agricultural soils. Lime and dolomite are added by land managers to ameliorate acidification. When these compounds come in contact with acid soils, they degrade, thereby generating CO_2. The rate and ultimate magnitude of degradation of applied limestone and dolomite depends on the soil conditions, climate regime, and the type of mineral applied.

Cropland Remaining Cropland includes all areas designated as cropland that had been cropland since 1982 according to the USDA NRI land use survey (USDA-NRCS 2000). Consequently, the area of *Cropland Remaining Cropland* changes through time with land-use change. For this area, CO_2 emissions and removals[5] due to changes in mineral soil C stocks are estimated using a Tier 3 approach for the majority of annual crops. A Tier 2 IPCC method is used for the remaining crops (vegetables, tobacco, perennial/horticultural crops, and rice) not included in the Tier 3 method. In addition, a Tier 2 method is used for very gravelly, cobbly or shaley soils (i.e., classified as soils that have greater than 35 percent of soil volume comprised of gravel, cobbles or shale) and for additional changes in mineral soil C stocks that were not addressed with the Tier 2 or 3 approaches (i.e., change in C stocks after 1997 due to Conservation Reserve Program enrollment). Emissions from organic soils are estimated using a Tier 2 IPCC method. Emissions from liming are estimated using a Tier 2 IPCC method that relies on national aggregate statistics of lime application and emissions factors developed by West and McBride (2005).

Of the three sub-source categories, land-use and land management of mineral soils was the most important component of total net C stock change between 1990 and 2005 (see Table 7-16 and Table 7-17). In 2005, mineral soils were estimated to remove about 71.1 Tg CO_2 Eq. (19.4 Tg C). This rate of C storage in mineral soils represented about an 18 percent increase in the rate since the initial reporting year of 1990. Emissions from organic soils had the second largest flux, emitting about 27.7 Tg CO_2 Eq. (7.5 Tg C) in 2005. Liming emitted another 4.0 Tg CO_2 Eq. (1.1 Tg C) in 2005. In total, U.S. agricultural soils in *Cropland Remaining Cropland* removed approximately 39.4 Tg CO_2 Eq. (10.7 Tg C) in 2005.

Table 7-16: Net Soil C Stock Changes and Liming Emissions in *Cropland Remaining Cropland* (Tg CO_2 Eq.)

Soil Type	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Mineral Soils	(60.2)	(69.5)	(68.5)	(70.1)	(70.4)	(70.5)	(71.0)	(71.1)
Organic Soils	27.4	27.7	27.7	27.7	27.7	27.7	27.7	27.7
Liming of Soils[1]	4.7	4.4	4.3	4.4	5.0	4.6	3.9	4.0
Total Net Flux	**(28.1)**	**(37.4)**	**(36.5)**	**(38.0)**	**(37.8)**	**(38.3)**	**(39.4)**	**(39.4)**

Note: Parentheses indicate net sequestration. Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only. Totals may not sum due to independent rounding.
[1] Also includes emissions from liming on *Land Converted to Cropland, Grassland Remaining Grassland,* and *Land Converted to Grassland.*

Table 7-17: Net Soil C Stock Changes and Liming Emissions in *Cropland Remaining Cropland* (Tg C)

Soil Type	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Mineral Soils	(16.4)	(18.9)	(18.7)	(19.1)	(19.2)	(19.2)	(19.4)	(19.4)
Organic Soils	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Liming of Soils[1]	1.3	1.2	1.2	1.2	1.4	1.2	1.1	1.1
Total Net Flux	**(7.7)**	**(10.2)**	**(10.0)**	**(10.4)**	**(10.3)**	**(10.4)**	**(10.7)**	**(10.7)**

Note: Parentheses indicate net sequestration. Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only. Totals may not sum due to independent rounding.
[1] Also includes emissions from liming in *Land Converted to Cropland, Grassland Remaining Grassland,* and *Land Converted to Grassland.*

The net increase in soil C stocks over the period from 1990 through 2005 was largely due to an increase in annual cropland enrolled in the Conservation Reserve Program, intensification of crop production by limiting the use of bare-summer fallow in semi-arid regions, increased hay production, and adoption of conservation tillage (i.e., reduced- and no-till practices).

The spatial variability in annual CO_2 flux associated with C stock changes in mineral and organic soils is displayed

[5] Note that removals occur through crop and forage uptake of CO_2 into biomass C that is later incorporated into soils pools.

in Figure 7-4 and Figure 7-5. The highest rates of sequestration in mineral soils occurred in the Midwest, where there were the largest amounts of cropland managed with conservation tillage adoption. Rates were also high in the Great Plains due to enrollment in the Conservation Reserve Program. Emission rates from drained organic soils were highest along the southeastern coastal region, in the northeast central United States surrounding the Great Lakes, and along the central and northern portions of the west coast.

Figure 7-4: Net C Stock Change for Mineral Soils in *Cropland Remaining Cropland*, 2005

Figure 7-5: Net C Stock Change for Organic Soils in *Cropland Remaining Cropland*, 2005

The estimates presented here are restricted to C stock changes in agricultural soils. Agricultural soils are also important sources of other greenhouse gases, particularly N_2O from application of fertilizers, manure, and crop residues and from cultivation of legumes, as well as CH_4 from flooded rice cultivation. These emissions are accounted for in the Agriculture chapter, along with non-CO_2 greenhouse gas emissions from field burning of crop residues and CH_4 and N_2O emissions from livestock digestion and manure management.

Methodology

The following section includes a description of the methodology used to estimate changes in soil C stocks due to: (1) agricultural land-use and management activities on mineral soils; (2) agricultural land-use and management activities on organic soils; and (3) CO_2 emissions that result from liming of soils with dolomite and limestone for *Cropland Remaining Cropland*.

Soil C stock changes were estimated for *Cropland Remaining Cropland* (as well as agricultural land falling into the IPCC categories *Land Converted to Cropland*, *Grassland Remaining Grassland*, and *Land Converted to Grassland*) according to land use histories recorded in the USDA National Resources Inventory (NRI) survey (USDA-NRCS 2000). The NRI is a statistically-based sample of all non-federal land, and includes ca. 400,000 points in agricultural land of the conterminous United States and Hawaii.[6] Each point is associated with an "expansion factor" that allows scaling of C stock changes from NRI points to the entire country (i.e., each expansion factor represents the amount of area with the same land-use/management history as the sample point). Land-use and some management information (e.g., crop type, soil attributes, and irrigation) were collected for each NRI point on a 5-year cycle beginning in 1982, and were subdivided into four inventory time periods, 1980-84, 1985-1989, 1990-94 and 1995-2000. Currently, the NRI is being revised to collect data annually from a subset of points. However, at present, no additional inventory point data are available for years after 1997.

NRI points were classified as *Cropland Remaining Cropland* for an inventory time period (e.g., 1990-1994 and 1995-2000) if the land use had been cropland since the first year of the NRI survey in 1982 through the end of the respective time period. Cropland includes all land used to produce food or fiber, as well as forage that is harvested and used as feed (e.g., hay and silage).

Mineral Soil Carbon Stock Changes

A Tier 3 model-based approach was used to estimate C stock changes for mineral soils used to produce a majority of annual crops in the United States (i.e., all crops except vegetables, tobacco, perennial/horticultural crops, and rice in addition to lands with very gravelly, cobbly or shaley soils (greater than 35 percent by volume)). An IPCC Tier 2

[6] NRI points were classified as agricultural if under grassland or cropland management in 1992 and/or 1997.

method (see Ogle et al. 2003) was used to estimate C stock changes for cropland on mineral soils that were not addressed with the Tier 3 method: vegetables, tobacco, perennial/horticultural crops, rice, and crops rotated with these crops. The Tier 2 method was also used for very gravelly, cobbly or shaley soils. Mineral SOC stocks were estimated using a Tier 2 method for these areas, because the Century model used for the Tier 3 method has not been fully tested to address its adequacy for estimating C stock changes associated with certain crops and rotations, as well as cobbly, gravelly or shaley soils. An additional stock change calculation was made for mineral soils using Tier 2 emission factors. These calculations accounted for enrollment patterns in the Conservation Reserve Program after 1997, which was not addressed by the Tier 3 methods.

Further elaboration on the methodology and data used to estimate stock changes from mineral are described below and in Annex 3.13.

Tier 3 Approach

Mineral SOC stocks and stock changes were estimated using the Century biogeochemical model (Parton et al. 1987, 1988, 1994; Metherell et al. 1993), which simulates the dynamics of C and other elements in cropland, grassland, forest, and savanna ecosystems. It uses monthly weather data as input, along with information about soil physical properties. Input data on land use and management can be specified at monthly resolution and include land-use type, crop/forage type and management activities (e.g., planting, harvesting, fertilization, manure amendments, tillage, irrigation, residue removal, grazing, and fire). The model computes net primary productivity and C additions to soil, temperature, and water dynamics, in addition to turnover, stabilization, and mineralization of soil organic matter C and nutrient (N, K, S) elements. This method is more accurate than the Tier 1 and 2 approaches provided by the IPCC, because the simulation model treats changes as continuous over time rather than the simplified discrete changes represented in the default method (see Box 7-2 for additional information). National estimates were obtained by simulating historical land-use and management patterns as recorded in the USDA National Resources Inventory (NRI) survey. Land-use and management activities were grouped into inventory time periods (i.e., time "blocks") for 1980-84, 1985-89, 1990-94 and 1995-2000, using NRI data from 1982, 1987, 1992, and 1997, respectively.

[BEGIN BOX]

Box 7-2: Tier 3 Inventory for Soil C Stocks compared to Tier 1 or 2 Approaches

A Tier 3 model-based approach is used to inventory soil C stock changes on the majority of agricultural land with mineral soils. This approach entails several fundamental differences compared to the IPCC Tier 1 or 2 methods, which are based on a classification of land areas into a number of discrete states based on a highly aggregated classification of climate, soil, and management (i.e., only six climate regions, seven soil types and eleven management systems occur in U.S. agricultural land). Input variables to the Tier 3 model, including climate, soils, and management activities (e.g., fertilization, crop species, tillage, etc.), are represented in considerably more detail both temporally and spatially, and exhibit multi-dimensional interactions through the more complex model structure compared with the IPCC Tier 1 or 2 approach. The spatial resolution of the analysis is also finer in the Tier 3 method compared to the lower tier methods as implemented in the United States for previous inventories (e.g., 3,037 counties versus 181 Major Land Resource Areas (MLRAs), respectively).

In the Century model, soil C dynamics (and CO_2 emissions and uptake) are treated as continuous variables, which change on a monthly time step. C emissions and removals are an outcome of plant production and decomposition processes, which are simulated in the model structure. Thus, changes in soil C stocks are influenced by not only changes in land use and management but also inter-annual climate variability and secondary feedbacks between management activities, climate and soils as they affect primary production and decomposition. This latter characteristic constitutes one of the greatest differences between the methods, and forms the basis for a more complete accounting of soil C stock changes in the Tier 3 approach compared with Tier 2 methodology.

Because the Tier 3 model simulates a continuous time period rather than as an equilibrium step change used in the IPCC methodology (Tier 1 and 2), the Tier 3 model addresses the delayed response of the soil to management and land-use changes, which can occur due to variable weather patterns and other environmental constraints that interact with land use and management and affect the time frame over which stock changes occur. Moreover, the Tier 3 method also accounts for the overall effect of increasing yields and, hence, C input to soils that have taken place across management systems and crop types within the United States. Productivity has increased by 1 to 2 percent annually over the past 4 to 5 decades for most major crops in the United States (Reilly and Fuglie 1998), which is believed to have led to increases in cropland soil C stocks (e.g., Allmaras et al. 2000). This is a major difference from the IPCC-based Tier 1 and 2 approaches, in which soil C stocks change only with discrete changes in management and/or land use, rather than a longer term trend such as gradual increases in crop productivity.

[END BOX]

Additional sources of activity data were used to supplement the land-use information from NRI. The Conservation Technology Information Center (CTIC 1998) provided annual data on tillage activity at the county level since 1989, with adjustments for long-term adoption of no-till agriculture (Towery 2001). Information on fertilizer use and rates by crop type for different regions of the United States were obtained primarily from the USDA Economic Research Service Cropping Practices Survey (ERS 1997) with additional data from other sources, including the National Agricultural Statistics Service (NASS 1992, 1999, 2004). Frequency and rates of manure application to cropland during 1997 were estimated from data compiled by the USDA Natural Resources Conservation Service (Edmonds et al. 2003), and adjusted based on county-level manure production rates for other years in the inventory. Specifically, county-scale ratios of manure production in other years relative to 1997 were used to estimate the area amended in the other years, essentially scaling the amendment data compiled by USDA in 1997 across the time series (see Annex 3.13 for further details). Higher managed manure N production relative to 1997 was, thus, assumed to increase the amount of area amended with manure, while less managed manure N production relative to 1997 was assumed to reduce the amended area. The amount of managed manure produced by each livestock type was calculated by determining the population of animals that were on feedlots or otherwise housed (requiring manure to be collected and managed). Annual animal population data for all livestock types, except horses and goats, were obtained for all years from the U.S. Department of Agriculture-National Agricultural Statistics Service (USDA 1994a-b, 1995a-b, 1998a-b, 1999a-c, 2000, 2004a-e, 2005a-e, 2006a-e). Horse population data were obtained from the FAOSTAT database (FAO 2006). Goat population data for 1992, 1997, and 2002 were obtained from the Census of Agriculture (USDA 2005f); these data were interpolated and extrapolated to derive estimates for the other years. Information regarding poultry turnover (i.e., slaughter) rate was obtained from state Natural Resource Conservation Service personnel (Lange 2000). Additional population data for different farm size categories for dairy and swine were obtained from the 1992 and 1997 *Census of Agriculture* (USDA 2005g).

Monthly weather data, aggregated to county-scale from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) database (Daly et al. 1994), were used as an input in the model simulations. Soil attributes were obtained from an NRI database, which were assigned based on field visits and soil series descriptions. Where more than one inventory point was located in the same county (i.e., same weather) and having the same land-use/management histories and soil type, data inputs to the model were identical and, therefore, these points were clustered for simulation purposes. For the 370,738 NRI points representing non-federal cropland and grassland, there were a total of 170,279 clustered points that represent the unique combinations of climate, soils, land use, and management in the modeled data set. Each NRI cluster point was run 100 times as part of the uncertainty assessment, yielding a total of over 14 million simulation runs for the analysis. C stock estimates from Century were adjusted using a structural uncertainty estimator accounting for uncertainty in model algorithms and parameter values (Ogle et al. 2007). Mean changes in C stocks and 95 percent confidence intervals were estimated for 1990 to 1994 and 1995 to 2000 (see Uncertainty section for more details). C stock changes from 2001 to 2005 were assumed to be similar to the 1995 to 2000 block, because no additional activity data are currently available from the NRI for the latter years.

Tier 2 Approach

In the Tier 2 method, data on climate, soil types, land-use and land management activity were used to classify land area to apply appropriate stock change factors. MLRAs formed the base spatial unit for mapping climate regions in the United States; each MLRA represents a geographic unit with relatively similar soils, climate, water resources, and land uses (NRCS 1981).[7] MLRAs were classified into climate regions according to the IPCC categories using the PRISM climate database of Daly et al. (1994).

Reference C stocks were estimated using the National Soil Survey Characterization Database (NRCS 1997) with cultivated cropland as the reference condition, rather than native vegetation as used in IPCC/UNEP/OECD/IEA (1997) and IPCC (2003). Changing the reference condition was necessary because soil measurements under agricultural management are much more common and easily identified in the National Soil Survey Characterization Database (NRCS 1997) than those that are not considered cultivated cropland.

U.S.-specific stock change factors were derived from published literature to determine the impact of management practices on SOC storage, including changes in tillage, cropping rotations and intensification, and land-use change between cultivated and uncultivated conditions (Ogle et al. 2003, Ogle et al. 2006).[8] U.S. factors associated with organic matter amendments were not estimated because of an insufficient number of studies to analyze those impacts. Instead, factors from IPCC (2003) were used to estimate the effect of those activities. Euliss and Gleason (2002) provided the data for computing the change in SOC storage resulting from restoration of wetland enrolled in the Conservation Reserve Program.

Similar to the Tier 3 Century method, activity data were primarily based on the historical land-use/management patterns recorded in the NRI. Each NRI point was classified by land use, soil type, climate region (using PRISM data, Daly et al. 1994) and management condition. Classification of cropland area by tillage practice was based on data from the Conservation Tillage Information Center (CTIC 1998, Towery 2001) as described above. Activity data on wetland restoration of Conservation Reserve Program land were obtained from Euliss and Gleason (2002). Manure N amendments over the inventory time period were based on application rates and areas amended with manure N from Edmonds et al. (2003), in addition to the managed manure production data discussed in the previous methodology subsection on the Tier 3 analysis for mineral soils.

Combining information from these data sources, SOC stocks for mineral soils were estimated 50,000 times for 1982, 1992, and 1997, using a Monte Carlo simulation approach and the probability distribution functions for U.S.-specific stock change factors, reference C stocks, and land-use activity data (Ogle et al. 2002, Ogle et al. 2003). The annual C flux for 1990 through 1992 was determined by calculating the average annual change in stocks between 1982 and 1992; annual C flux for 1993 through 2005 was determined by calculating the average annual change in stocks between 1992 and 1997.

Additional Mineral C Stock Change

Annual C flux estimates for mineral soils between 1990 and 2005 were adjusted to account for additional C stock changes associated with gains or losses in soil C after 1997 due to changes in Conservation Reserve Program enrollment. The change in enrollment acreage relative to 1997 was based on data from FSA (2006) for 1998 through 2005, and the differences in mineral soil areas were multiplied by 0.5 metric tons C per hectare per year to estimate the net effect on soil C stocks. The stock change rate is based on estimations using the IPCC method (see Annex 3.13 for further discussion).

[7] The polygons displayed in Figure 7-7 through Figure 7-10 are the Major Land Resource Areas.

[8] Stock change factors have been derived from published literature to reflect changes in tillage, cropping rotations and intensification, land-use change between cultivated and uncultivated conditions, and drainage of organic soils.

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Cropland Remaining Cropland* were estimated using the Tier 2 method provided in IPCC/UNEP/OECD/IEA (1997) and IPCC (2003), which utilizes U.S.-specific C loss rates (Ogle et al. 2003) rather than default IPCC rates. Similar to the Tier 2 analysis for mineral soils, the final estimates included a measure of uncertainty as determined from the Monte Carlo simulation with 50,000 iterations. Emissions were based on the 1992 and 1997 *Cropland Remaining Cropland* areas from the *1997 National Resources Inventory* (USDA-NRCS 2000). The annual flux estimated for 1992 was applied to 1990 through 1992, and the annual flux estimated for 1997 was applied to 1993 through 2005.

CO_2 Emissions from Agricultural Liming

Carbon dioxide emissions from degradation of limestone and dolomite applied to agricultural soils were estimated using a Tier 2 methodology. The annual amounts of limestone and dolomite applied (see Table 7-18) were multiplied by CO_2 emission factors from West and McBride (2005). These emission factors (0.059 metric ton C/metric ton limestone, 0.064 metric ton C/metric ton dolomite) are lower than the IPCC default emission factors, because they account for the portion of agricultural lime that may leach through the soil and travel by rivers to the ocean (West and McBride 2005). The annual application rates of limestone and dolomite were derived from estimates and industry statistics provided in the *Minerals Yearbook* and *Mineral Industry Surveys* (Tepordei 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006; USGS 2006). To develop these data, the U.S. Geological Survey (USGS; U.S. Bureau of Mines prior to 1997) obtained production and use information by surveying crushed stone manufacturers. Because some manufacturers were reluctant to provide information, the estimates of total crushed limestone and dolomite production and use were divided into three components: 1) production by end-use, as reported by manufacturers (i.e., "specified" production); 2) production reported by manufacturers without end-uses specified (i.e., "unspecified" production); and 3) estimated additional production by manufacturers who did not respond to the survey (i.e., "estimated" production).

The "unspecified" and "estimated" amounts of crushed limestone and dolomite applied to agricultural soils were calculated by multiplying the percentage of total "specified" limestone and dolomite production applied to agricultural soils by the total amounts of "unspecified" and "estimated" limestone and dolomite production. In other words, the proportion of total "unspecified" and "estimated" crushed limestone and dolomite that was applied to agricultural soils (as opposed to other uses of the stone) was assumed to be proportionate to the amount of "specified" crushed limestone and dolomite that was applied to agricultural soils. In addition, data were not available for 1990, 1992, and 2005 on the fractions of total crushed stone production that were limestone and dolomite, and on the fractions of limestone and dolomite production that were applied to soils. To estimate the 1990 and 1992 data, a set of average fractions were calculated using the 1991 and 1993 data. These average fractions were applied to the quantity of "total crushed stone produced or used" reported for 1990 and 1992 in the 1994 *Minerals Yearbook* (Tepordei 1996). To estimate 2005 data, the previous year's fractions were applied to a 2005 estimate of total crushed stone presented in the USGS *Mineral Industry Surveys: Crushed Stone and Sand and Gravel in the First Quarter of 2006* (USGS 2006).

The primary source for limestone and dolomite activity data is the *Minerals Yearbook*, published by the Bureau of Mines through 1994 and by the USGS from 1995 to the present. In 1994, the "Crushed Stone" chapter in the *Minerals Yearbook* began rounding (to the nearest thousand) quantities for total crushed stone produced or used. It then reported revised (rounded) quantities for each of the years from 1990 to 1993. In order to minimize the inconsistencies in the activity data, these revised production numbers have been used in all of the subsequent calculations.

Table 7-18: Applied Minerals (Million Metric Tons)

Mineral	**1990**		**1995**		**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Limestone	19.01		17.30		15.86	16.10	20.45	18.71	15.50	16.10
Dolomite	2.36		2.77		3.81	3.95	2.35	2.25	2.33	2.42

Note: These numbers represent amounts applied to all agricultural land, not just *Cropland Remaining Cropland*.

Uncertainty

Uncertainty associated with the *Cropland Remaining Cropland* land-use category was addressed for changes in agricultural soil C stocks (including both mineral and organic soils) and soil liming emissions. Uncertainty estimates are presented in Table 7-19 for each subsource (i.e., mineral soil C stocks, organic soil C stocks, soil liming) disaggregated to the level of the inventory methodology employed (i.e., Tier 2 and Tier 3). A combined uncertainty estimate for changes in soil C stocks occurring within *Cropland Remaining Cropland* is also included. Uncertainty estimates from each component were combined using the error propagation equation in accordance with IPCC (2006). The combined uncertainty was calculated by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. More details on how the individual uncertainties were developed appear later in this section. The combined uncertainty for soil C stocks in *Cropland Remaining Cropland* ranged from 43 percent below and 38 percent above the 2005 stock change estimate of -39.4 Tg CO_2 Eq.

Table 7-19: Quantitative Uncertainty Estimates for C Stock Changes occurring within *Cropland Remaining Cropland* (Tg CO_2 Eq. and Percent)

Source	2005 Stock Change Estimate (Tg CO_2 Eq.)	Uncertainty Range Relative to Stock Change Estimate (Tg CO_2 Eq.)		Uncertainty Range Relative to Stock Change Estimate (%)	
		Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Mineral Soil C Stocks: *Cropland Remaining Cropland*, Tier 3 Inventory Methodology	(66.4)	(77.0)	(55.9)	-16%	+16%
Mineral Soil C Stocks: *Cropland Remaining Cropland*, Tier 2 Inventory Methodology	(3.0)	(6.9)	0.8	-127%	+128%
Mineral Soil C Stocks: *Cropland Remaining Cropland* (Change in CRP enrollment relative to 1997)	(1.6)	(2.5)	(0.8)	-50%	+50%
Organic Soil C Stocks: *Cropland Remaining Cropland*, Tier 2 Inventory Methodology	27.7	15.8	36.9	-43%	+33%
CO_2 Emissions from Liming	4.0	0.2	8.0	-96%	98%
Combined Uncertainty for Agricultural Soil C Stocks in *Cropland Remaining Cropland*	**(39.4)**	**(56.2)**	**(24.3)**	**-43%**	**+38%**

QA/QC and Verification

Quality control measures included checking input data, model scripts, and results to ensure data were properly handled through the inventory process. Errors were found in these steps and corrective actions were taken. One of the errors involved a subset of the transitions from full tillage to reduced till between the late 1980s and early 1990s. The reduced tillage transition was not occurring and the script was revised to correct the transition. The second error involved improved estimation of root production in irrigated systems. Root production had been parameterized based on rainfed crops, and so the parameters were adjusted to better approximate C allocation to belowground growth in irrigated lands. In addition, QA/QC activities uncovered that the empirically-based structural uncertainty estimator for the Century model did not address the random variation associated with predicting soil C stock changes at the site level in the previous inventory, which is equivalent to NRI points. This uncertainty is not insignificant, and, thus, previous uncertainty estimates were unrealistically low because the random variation was not addressed. Adjustments were made in the current inventory, and the results better reflect the uncertainty in the Tier 3 approach as implemented in the United States.

As discussed in the uncertainty sections, results were compared to field measurements, and a statistical relationship was developed to assess uncertainties in the model's predictive capability. The comparisons included over 40 long-term experiments, representing about 800 combinations of management treatments across all of the sites (Ogle et al. 2007). Inventory reporting forms and text were reviewed and revised as needed to correct transcription errors.

Recalculations Discussion

Several adjustments were made in the current inventory to improve the results. First, consistency was achieved in the N inputs data between the agricultural soil C and soil N_2O source categories (see Agricultural Soil Management section of the Agriculture chapter). Although this improvement required several changes to soil N_2O inventory methods, the only change to the soil C source was the scaling of manure amendment data in 1997 based on variation in managed manure N production during other years of the Inventory. Second, scheduling files, (used in the model program to determine when activities such as fertilization, tillage, planting, and harvesting occur) were adjusted in the Tier 3 approach, so that transitions from full tillage to reduced till were properly modeled, and allocation of C to roots was reduced for irrigated systems due to excessively high root biomass discovered through QA/QC checks. Third, uncertainty was estimated in the current inventory for the random variation associated with Century model estimates at the site scale. This is a significant uncertainty in the assessment framework, which was not addressed in the previous inventory. Fourth, annual C emissions from organic cropland soils are subdivided between *Cropland Remaining Cropland* and *Land Converted to Cropland*. In the previous inventory, all C emissions associated with drainage of organic soils for crop production were reported in the *Cropland Remaining Cropland* category.

The quantity of applied minerals reported in the previous inventory for 2004 has been revised. Consequently, the reported emissions resulting from liming in 2004 have also changed. In the previous inventory, to estimate 2004 data, the previous year's fractions were applied to a 2004 estimate of total crushed stone presented in the USGS *Mineral Industry Surveys: Crushed Stone and Sand and Gravel in the First Quarter of 2005* (USGS 2005). Since publication of the previous inventory, the *Minerals Yearbook* has published actual quantities of crushed stone sold or used by producers in the United States in 2004. These values have replaced those used in the previous inventory to calculate the quantity of minerals applied to soil and the emissions from liming. Additionally, a correction was made to liming activity data from 2003 that was inaccurately transcribed from the original source.

Overall, the recalculations resulted in an average annual increase in sinks of 5.3 Tg CO_2 Eq. (21 percent) for soil C stock changes in *Cropland Remaining Cropland* for the period 1990 through 2004.

Planned Improvements

Several improvements are planned for the agricultural soil C inventory. The first improvement is to incorporate new land-use and management activity data from the NRI. In the current inventory, NRI data only provide land-use and management statistics through 1997, but it is anticipated that new statistics will be released in the coming year for 2000 through 2003. The new data will greatly improve the accuracy of land-use and management influences on soil C in the latter part of the time series.

The second improvement is to develop a consistent representation of the U.S. managed land base. More details on this planned improvement are provided in the *Forest Land Remaining Forest Land* section.

The third improvement is to incorporate additional crops into the Tier 3 approach. Currently, crops such as vegetables, rice, perennial and horticultural crops have not been fully implemented in the Century model application. However, efforts are currently underway to further develop the model application for simulating soil C dynamics in land managed for production of these crops.

The fourth improvement is to incorporate remote sensing in the analysis for estimation of crop and forage production. Specifically, the Enhanced Vegetation Index (EVI) product that is derived from MODIS satellite imagery is being used to refine the production estimation for the Tier 3 assessment framework. EVI reflects changes in plant "greenness" over the growing season and can be used to compute production based on the light use efficiency of the crop or forage (Potter et al. 1993). In the current framework, production is simulated based on the weather data, soil characteristics, and the genetic potential of the crop. While this method produces reasonable results, remote sensing can be used to refine the productivity estimates and reduce biases in crop production and subsequent C input to soil systems. It is anticipated that precision in the Tier 3 assessment framework will be increased by 25 percent or more with the new method.

The fifth improvement is to develop an automated quality control system to evaluate the results from Century model simulations. Currently, there are over 14 million simulations, and it is not possible to manually review each single simulation. Results are aggregated and evaluated at larger scales such as Major Land Resource Areas and States. QA/QC at these larger scales may not uncover errors at the scale of individual NRI points, which is the scale at which the Century model is used to simulate soil C dynamics. An automated system would greatly improve QA/QC, performing checks on the results from each simulation and identifying errors for further refinements.

The last improvement is to further develop the uncertainty analysis for the Tier 3 method by addressing the uncertainty inherent in the Century model results for other agricultural land (i.e., *Grassland Remaining Grassland*, *Land Converted to Grassland*, and *Land Converted to Cropland*). In addition, uncertainties need to be addressed in the simulation of soil C stocks for the pre-NRI time period (i.e., before 1979). In the current analysis, inventory development focused on uncertainties in the last two decades because the management activity during the most recent time periods will likely have the largest impact on current trends in soil C storage. However, legacy effects of past management can also have a significant effect on current C stock trends, as well as trajectories of those C stocks in the near future. Therefore, a planned improvement is to revise the inventory to address uncertainties in management activity prior to 1979.

7.4. Land Converted to Cropland (IPCC Source Category 5B2)

Land Converted to Cropland includes all areas designated as cropland that had been another land use in a prior time period according to the USDA NRI land use survey (USDA-NRCS 2000). Consequently, the area considered in *Land Converted to Cropland* changes through time with land-use change. Lands are retained in this category for 20 years as recommended by the IPCC guidelines (IPCC 2006) unless there is another land-use change. Background on agricultural C stock changes is provided in *Cropland Remaining Cropland* and will only be summarized here for *Land Converted to Cropland*. Soils are the largest pool of C in agricultural land, and also have the greatest potential for storage or release of C, because biomass and dead organic matter C pools are relatively small and ephemeral compared with soils. The IPCC/UNEP/OECD/IEA (1997) and the IPCC (2003) recommend reporting changes in soil organic C stocks due to: (1) agricultural land-use and management activities on mineral soils, (2) agricultural land-use and management activities on organic soils, and (3) CO_2 emissions that result from liming of soils with dolomite and limestone. Mineral soil C stock changes and C emissions from drained and cultivated organic soils are reported for *Land Converted to Cropland*. It was not possible, however, to subdivide the liming application estimates by land use/land-use change categories (see Methodology section below for additional discussion)

Land-use and management of mineral soils in *Land Converted to Cropland* led to losses of soil C during the early 1990s but losses declined slightly through the latter part of the time series (Table 7-20 and Table 7-21). The rate of change in soil C stocks was 7.2 Tg CO_2 Eq. (2.0 Tg C) in 2005. Emissions from mineral soils were estimated at 4.6 Tg CO_2 Eq. (1.2 Tg C) in 2005, while drainage and cultivation of organic soils led to annual losses of 2.6 Tg CO_2 Eq. (0.7 Tg C) in 2005.

Table 7-20: Net Soil C Stock Changes in *Land Converted to Cropland* (Tg CO_2 Eq.)

Soil Type	1990	1995	2000	2001	2002	2003	2004	2005
Mineral Soils	6.2	4.6	4.6	4.6	4.6	4.6	4.6	4.6
Organic Soils	2.4	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Liming of Soils[1]	-	-	-	-	-	-	-	-
Total Net Flux	**8.7**	**7.2**	**7.2**	**7.2**	**7.2**	**7.2**	**7.2**	**7.2**

[1] Emissions from liming in *Land Converted to Cropland* are reported in *Cropland Remaining Cropland*
Note: Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only. Totals may not sum due to independent rounding.

Table 7-21: Net Soil C Stock Changes in *Land Converted to Cropland* (Tg C)

Soil Type	1990	1995	2000	2001	2002	2003	2004	2005
Mineral Soils	1.7	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Organic Soils	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Liming of Soils[1]	-	-	-	-	-	-	-	-

Total Net Flux	**2.4**		**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**

[1] Emissions from liming in *Land Converted to Cropland* are reported in *Cropland Remaining Cropland*
Note: Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only. Totals may not sum due to independent rounding.

The spatial variability in annual CO_2 flux associated with C stock changes in mineral and organic soils for *Land Converted to Cropland* is displayed in Figure 7-6 and Figure 7-7. While a large portion of the United States had net losses in soil C for *Land Converted to Cropland*, there were some notable areas with sequestration in the Intermountain West and Central United States. These areas were gaining C following conversion, because croplands were irrigated or receiving higher fertilizer inputs relative to the previous land use. Emissions from organic soils were largest in California, Florida and the upper Midwest, which coincided with largest concentrations of cultivated organic soils in the United States.

Figure 7-6: Net C Stock Change for Mineral Soils in *Land Converted to Cropland*, 2005

Figure 7-7: Net C Stock Change for Organic Soils in *Land Converted to Cropland*, 2005

Methodology

The following section includes a brief description of the methodology used to estimate changes in soil C stocks due to agricultural land-use and management activities on mineral and organic soils for *Land Converted to Cropland*.

Soil C stock changes were estimated for *Land Converted to Cropland* according to land-use histories recorded in the USDA NRI survey (USDA-NRCS 2000).[9] Land use and some management information (e.g., crop type, soil attributes, and irrigation) were collected for each NRI point on a 5-year cycle beginning in 1982, and were subdivided into four inventory time periods, 1980-84, 1985-1989, 1990-94 and 1995-2000. NRI points were classified as *Land Converted to Cropland* for an inventory time period (e.g., 1990-1994 and 1995-2000) if the land use was cropland at the end of the respective inventory time period but had been another use in a prior inventory time period. Cropland includes all land used to produce food or fiber, as well as forage that is harvested and used as feed (e.g., hay and silage). Further elaboration on the methodologies and data used to estimate stock changes for mineral and organic soils are provided in the *Cropland Remaining Cropland* section and Annex 3.13.

Mineral Soil Carbon Stock Changes

A Tier 3 model-based approach was used to estimate C stock changes for soils on *Land Converted to Cropland* used to produce a majority of all crops. Exceptions, which relied on an IPCC Tier 2 method to estimate C stock changes, included: land used to produce vegetable, tobacco, perennial/horticultural crops, and rice; land on very gravelly, cobbly or shaley soils (greater than 35 percent by volume); and land converted from forest or federal ownership.[10] (Ogle et al. 2003)

Tier 3 Approach

Mineral SOC stocks and stock changes were estimated using the Century biogeochemical model for the Tier 3

[9] NRI points were classified as agricultural if under grassland or cropland management in 1992 and/or 1997.
[10] Federal land is not a land use, but rather an ownership designation that is treated as forest or nominal grassland for purposes of these calculations. The specific use for federal lands is not identified in the NRI survey (USDA-NRCS 2000).

methods. National estimates were obtained by using the model to simulate historical land-use change patterns as recorded in the USDA National Resources Inventory (USDA-NRCS 2000). The methods used for *Land Converted to Cropland* are the same as those described in the Tier 3 portion of *Cropland Remaining Cropland* Section for mineral soils (see *Cropland Remaining Cropland* Tier 3 methods section for additional information).

Tier 2 Approach

For the mineral soils not included in the Tier 3 analysis, SOC stock changes were estimated using a Tier 2 Approach for *Land Converted to Cropland* as described in the Tier 2 portion of *Cropland Remaining Cropland* Section for mineral soils (see *Cropland Remaining Cropland* Tier 2 methods section for additional information).

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Land Converted to Cropland* were estimated using the Tier 2 method provided in IPCC/UNEP/OECD/IEA (1997) and IPCC (2003), which utilizes U.S.-specific C loss rates (Ogle et al. 2003) rather than default IPCC rates. The final estimates included a measure of uncertainty as determined from the Monte Carlo simulation with 50,000 iterations. Emissions were based on the 1992 and 1997 *Land Converted to Cropland* areas from the *1997 National Resources Inventory* (USDA-NRCS 2000). The annual flux estimated for 1992 was applied to 1990 through 1992, and the annual flux estimated for 1997 was applied to 1993 through 2005.

CO_2 Emissions from Agricultural Liming

Carbon dioxide emissions from degradation of limestone and dolomite applied to *Land Converted to Cropland* are reported in *Cropland Remaining Cropland*, because it was not possible to disaggregate liming application among land use and land-use change categories.

Uncertainty

Uncertainty associated with the *Land Converted to Cropland* land-use change category includes the uncertainty associated with changes in mineral and organic soil C stocks. Uncertainty estimates are presented in Table 7-22 for each subsource (i.e., mineral soil C stocks and organic soil C stocks) disaggregated to the level of the Inventory methodology employed (i.e., Tier 2 and Tier 3). A combined uncertainty estimate for changes in agricultural soil C stocks occurring within *Land Converted to Cropland* is also included. Uncertainty estimates from each component were combined using the error propagation equation in accordance with IPCC (2006). The combined uncertainty was calculated by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. More details on how the individual uncertainties were developed appear later in this section. The combined uncertainty for soil C stocks in *Land Converted to Cropland* was estimated to be 33 percent below and 29 percent above the inventory estimate of 7.2 Tg CO_2 Eq.

Table 7-22: Quantitative Uncertainty Estimates for C Stock Changes occurring within *Land Converted to Cropland* (Tg CO_2 Eq. and Percent)

Source	2005 Stock Change Estimate (Tg CO_2 Eq.)	Uncertainty Range Relative to Stock Change Estimate (Tg CO_2 Eq.)		Uncertainty Range Relative to Stock Change Estimate (%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mineral Soil C Stocks: *Land Converted to Cropland*, Tier 3 Inventory Methodology	0.4	(0.1)	0.9	-124%	+124%
Mineral Soil C Stocks: *Land Converted to Cropland*, Tier 2 Inventory Methodology	4.1	2.3	5.8	-44%	+41%
Organic Soil C Stocks: *Land Converted to Cropland*, Tier 2 Inventory Methodology	2.6	1.2	3.7	-53%	+41%
Combined Uncertainty for Agricultural Soil	**7.2**	**4.9**	**9.3**	**-33%**	**29%**

Carbon Stocks in *Land Converted to Cropland*	

Uncertainties in Mineral Soil Carbon Stock Changes

The uncertainty analysis for *Land Converted to Cropland* using the Tier 3 and 2 approaches were based on the same method described for *Cropland Remaining Cropland*, except that the uncertainty inherent in the structure of the Century model was not addressed.

Uncertainties in Organic Soil Carbon Stock Changes

Annual C emission estimates from drained organic soils in *Land Converted to Cropland* were estimated using the Tier 2 Approach, as described in the *Cropland Remaining Cropland* Section.

QA/QC and Verification

See QA/QC and Verification Section under *Cropland Remaining Cropland*.

Recalculations Discussion

The specific changes in reporting in the current Inventory for *Land Converted to Cropland* are the same as those described in the *Cropland Remaining Cropland* section, except that the uncertainty is not addressed for the random variation associated with Century model estimates at the site scale. The structural uncertainty requires further development before it can be used to address uncertainty inherent in the structure of the Century model for *Land Converted to Cropland*. A further change affecting this section is that organic soil emissions for the *Cropland Remaining Cropland* and *Land Converted to Cropland* sections were previously reported together in the *Cropland Remaining Cropland* section. For the current inventory, they have been reapportioned between the land use categories and, therefore, a portion of the emissions are now reported in the *Land Converted to Cropland* section. Overall, these recalculations resulted in an average annual increase in emissions of 9.1 Tg CO_2 Eq. (71.4 percent) for soil C stock changes in *Land Converted to Cropland* over the time series from 1990 through 2004. The changes also resulted in a shift from the previous inventory's reporting of this category as an overall sink to the current reporting as an overall source.

Planned Improvements

The empirically-based uncertainty estimator described in the *Cropland Remaining Cropland* section for the Tier 3 approach has not been developed to estimate uncertainties related to the structure of Century model for *Land Converted to Cropland,* but this is a planned improvement. See Planned Improvements section under *Cropland Remaining Cropland* for additional planned improvements.

7.5. Grassland Remaining Grassland (IPCC Source Category 5C1)

Grassland Remaining Grassland includes all areas of grassland that had been designated as grassland since 1982 according to the USDA NRI land use survey (USDA-NRCS 2000). Consequently, the area considered in *Grassland Remaining Grassland* changes through time with land-use change. Background on agricultural C stock changes is provided in the *Cropland Remaining Cropland* section and will only be summarized here for *Grassland Remaining Grassland*. Soils are the largest pool of C in agricultural land, and also have the greatest potential for storage or release of C, because biomass and dead organic matter C pools are relatively small and ephemeral compared to soils. The IPCC/UNEP/OECD/IEA (1997) and IPCC (2003) recommend reporting changes in soil organic C stocks due to: (1) agricultural land-use and management activities on mineral soils, (2) agricultural land-use and management activities on organic soils, and (3) CO_2 emissions that result from liming of soils with dolomite and limestone. Mineral and organic soil C stock changes are reported here for *Grassland Remaining Grassland*, but stock changes associated with liming are reported in *Cropland Remaining Cropland,* because it was not possible to subdivide those estimates by land use/land-use change categories (see Methodology section below for additional discussion).

Land-use and management of mineral soils in *Grassland Remaining Grassland* increased soil C during the early 1990s, but this trend was reversed over the decade, with small losses of C prevailing during the latter part of the time series (see Table 7-23 and Table 7-24). Organic soils lost about the same amount of C in each year of the inventory. The overall trend shifted from small decreases in soil C during 1990 to larger decreases during the latter years, estimated at 16.1 Tg CO_2 Eq. (4.4 Tg C) in 2005.

Table 7-23: Net Soil C Stock Changes in *Grassland Remaining Grassland* (Tg CO_2 Eq.)

Soil Type	1990	1995	2000	2001	2002	2003	2004	2005
Mineral Soils	(3.7)	12.7	12.6	12.6	12.5	12.5	12.5	12.4
Organic Soils	3.9	3.7	3.7	3.7	3.7	3.7	3.7	3.7
Liming of Soils[1]	-	-	-	-	-	-	-	-
Total Net Flux	**0.1**	**16.4**	**16.3**	**16.2**	**16.2**	**16.2**	**16.1**	**16.1**

Note: Parentheses indicate net sequestration. Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only. Totals may not sum due to independent rounding.
[1] Emissions from liming in *Grassland Remaining Grassland* are reported in *Cropland Remaining Cropland*.

Table 7-24: Net Soil C Stock Changes in *Grassland Remaining Grassland* (Tg C)

Soil Type	1990	1995	2000	2001	2002	2003	2004	2005
Mineral Soils	(1.0)	3.5	3.4	3.4	3.4	3.4	3.4	3.4
Organic Soils	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Liming of Soils[1]	-	-	-	-	-	-	-	-
Total Net Flux	**0**	**4.5**	**4.4**	**4.4**	**4.4**	**4.4**	**4.4**	**4.4**

Note: Parentheses indicate net sequestration. Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only. Totals may not sum due to independent rounding.
[1] Emissions from liming in *Grassland Remaining Grassland* are reported in *Cropland Remaining Cropland*.

The spatial variability in annual CO_2 flux associated with C stock changes in mineral and organic soils is displayed in Figure 7-8 and Figure 7-9. Grassland is losing soil organic C in the United States largely due to droughts that are causing small losses of C on a per hectare basis, but are occurring over a large land base. In areas with net gains in soil organic C, sequestration was driven by irrigation and seeding legumes. Similar to *Cropland Remaining Cropland*, emission rates from drained organic soils were highest along the southeastern coastal region, in the northeast central United States surrounding the Great Lakes, and along the central and northern portions of the west coast.

Figure 7-8: Net Soil C Stock Change for Mineral Soils in *Grassland Remaining Grassland*, 2005

Figure 7-9: Net Soil C Stock Change for Organic Soils in *Grassland Remaining Grassland*, 2005

Methodology

The following section includes a brief description of the methodology used to estimate changes in soil C stocks due to agricultural land-use and management activities on mineral and organic soils for *Grassland Remaining Grassland*.

Soil C stock changes were estimated for *Grassland Remaining Grassland* according to land-use histories recorded in the USDA NRI survey (USDA-NRCS 2000).[11] Land use and some management information (e.g., irrigation, legume pastures) were collected for each NRI point on a 5-year cycle beginning in 1982, 1980-84, 1985-1989, 1990-94 and 1995-2000. NRI points were classified as *Grassland Remaining Grassland* for an inventory time period (e.g., 1990-1994 and 1995-2000) if the land use had been grassland since the first year of the NRI survey in 1982 through the end of the respective time period. Grassland includes pasture and rangeland used for grass forage production, where the primary use is livestock grazing. Rangelands are typically extensive areas of native grassland that are not intensively managed, while pastures are often seeded grassland, possibly following tree removal, that may or may not be improved with practices such as irrigation and interseeding legumes. Further elaboration on the methodologies and data used to estimate stock changes from mineral and organic soils are provided in the *Cropland Remaining Cropland* section and Annex 3.13.

Mineral Soil Carbon Stock Changes

A Tier 3 model-based approach was used to estimate C stock changes for mineral soils in *Grassland Remaining Grassland*, except for lands with very gravelly, cobbly or shaley soils (greater than 35 percent by volume). An IPCC Tier 2 method was used to estimate stock changes for the gravelly, cobbly or shaley soils and additional changes in C stocks in mineral soils. A Tier 2 method was also used to estimate additional stock changes associated with sewage sludge amendments.

Tier 3 Approach

Mineral soil organic C stocks and stock changes for *Grassland Remaining Grassland* were estimated using the Century biogeochemical model, as described in *Cropland Remaining Cropland*. Historical land-use and management patterns were used in the Century simulations as recorded in the USDA National Resources Inventory (NRI) survey, with supplemental information on fertilizer use and rates from the USDA Economic Research Service Cropping Practices Survey (ERS 1997) and National Agricultural Statistics Service (NASS 1992, 1999, 2004). Frequency and rates of manure application to grassland during 1997 were estimated from data compiled by the USDA Natural Resources Conservation Service (Edmonds et al. 2003), and then adjusted using county-level manure production rates for other years in the inventory. Specifically, county-scale ratios of manure production in other years relative to 1997 were used to adjust the area amended with manure for other years in the inventory (see Annex 3.13 for further details). Higher managed manure N production relative to 1997 was, thus, assumed to increase the amount of area amended with manure, while less managed manure N production relative to 1997 was assumed to reduce the amended area. The amount of managed manure produced by each livestock type was calculated by determining the population of animals that were on feedlots or otherwise housed (requiring manure to be collected and managed). Annual animal population data for all livestock types, except horses and goats, were obtained for all years from the U.S. Department of Agriculture-National Agricultural Statistics Service (USDA 1994a-b, 1995a-b, 1998a-b, 1999a-c, 2000, 2004a-e, 2005a-d, 2006a-e). Horse population data were obtained from the FAOSTAT database (FAO 2006). Goat population data for 1992, 1997, and 2002 were obtained from the *Census of Agriculture* (USDA 2005g); these data were interpolated and extrapolated to derive estimates for the other years. Information regarding poultry turnover (i.e., slaughter) rate was obtained from state Natural Resource Conservation Service personnel (Lange 2000). Additional population data for different farm size categories for dairy and swine were obtained from the 1992 and 1997 *Census of Agriculture* (USDA 2005g).
Pasture/Range/Paddock (PRP) manure N deposition was estimated internally in the Century model, as part of the grassland system simulations (i.e., PRP manure deposition was not an external input into the model). See the Tier 3 methods in *Cropland Remaining Cropland* section for additional discussion on the Tier 3 methodology for mineral soils.

Tier 2 Approach

[11] NRI points were classified as agricultural if under grassland or cropland management in 1992 and/or 1997.

The Tier 2 approach is based on the same methods described in the Tier 2 portion of *Cropland Remaining Cropland* Section for mineral soils (see *Cropland Remaining Cropland* Tier 2 methods section for additional information).

Additional Mineral C Stock Change Calculations

Annual C flux estimates for mineral soils between 1990 and 2005 were adjusted to account for additional C stock changes associated with sewage sludge amendments using a Tier 2 method. Estimates of the amounts of sewage sludge N applied to agricultural land were derived from national data on sewage sludge generation, disposition, and nitrogen content. Total sewage sludge generation data for 1988, 1996, and 1998, and a projection for 2000, in dry mass units, were obtained from EPA reports (EPA 1993, 1999), and linearly interpolated to estimate values for the intervening years. N application rates from Kellogg et al. (2000) were used to determine the amount of area receiving sludge amendments. Although sewage sludge can be added to land managed for other land uses, it was assumed that agricultural amendments occur in grassland. Cropland is assumed to rarely be amended with sewage sludge due to the high metal content and other pollutants in human waste. The soil C storage rate was estimated at 0.38 metric tons C per hectare per year for sewage sludge amendments to grassland. The stock change rate is based on country-specific factors and the IPCC default method (see Annex 3.13 for further discussion).

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Grassland Remaining Grassland* were estimated using the Tier 2 method provided in IPCC/UNEP/OECD/IEA (1997) and IPCC (2003), which utilizes U.S.-specific C loss rates (Ogle et al. 2003) rather than default IPCC rates. The final estimates included a measure of uncertainty as determined from the Monte Carlo simulation with 50,000 iterations. Emissions were based on the 1992 and 1997 *Grassland Remaining Grassland* areas from the *1997 National Resources Inventory* (USDA-NRCS 2000). The annual flux estimated for 1992 was applied to 1990 through 1992, and the annual flux estimated for 1997 was applied to 1993 through 2005.

CO_2 Emissions from Agricultural Liming

Carbon dioxide emissions from degradation of limestone and dolomite applied to *Grassland Remaining Grassland* are reported in *Cropland Remaining Cropland*, because it was not possible to disaggregate liming application among land use/land-use change categories.

Uncertainty

Uncertainty associated with the *Grassland Remaining Grassland* category includes the uncertainty associated with changes in mineral and organic soil C stocks. Uncertainty estimates are presented in Table 7-25 for each subsource (i.e., mineral soil C stocks and organic soil C stocks) disaggregated to the level of the Inventory methodology employed (i.e., Tier 2 and Tier 3). A combined uncertainty estimate for changes in agricultural soil C stocks occurring within *Grassland Remaining Grassland* is also included. Uncertainty estimates from each component were combined using the error propagation equation in accordance with IPCC (2006). The combined uncertainty was calculated by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. More details on how the individual uncertainties were developed appear later in this section. The combined uncertainty for soil C stocks in *Grassland Remaining Grassland* was estimated to be 18 percent below and 15 percent above the inventory estimate of 16.1 Tg CO_2 Eq.

Table 7-25: Quantitative Uncertainty Estimates for C Stock Changes occurring within *Grassland Remaining Grassland* (Tg CO_2 Eq. and Percent)

Source	2005 Stock Change Estimate (Tg CO_2 Eq.)	Uncertainty Range Relative to Stock Change Estimate (Tg CO_2 Eq.)		Uncertainty Range Relative to Stock Change Estimate (%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mineral Soil C Stocks *Grassland Remaining Grassland*, Tier 3 Inventory Methodology	13.9	12.4	15.3	-10%	+10%

Mineral Soil C Stocks: *Grassland Remaining Grassland*, Tier 2 Inventory Methodology	(0.2)	(0.3)	0.04	-89%	+127%
Mineral Soil C Stocks: *Grassland Remaining Grassland* (Change in Soil C due to Sewage Sludge Amendments)	(1.3)	(1.9)	(0.6)	-50%	+50%
Organic Soil C Stocks: *Grassland Remaining Grassland*, Tier 2 Inventory Methodology	3.7	1.2	5.5	-66%	+49%
Combined Uncertainty for Agricultural Soil Carbon Stocks in *Grassland Remaining Grassland*	**16.1**	**13.2**	**18.5**	**-18%**	**+15%**

Uncertainties in Mineral Soil Carbon Stock Changes

Tier 3 Approach

The uncertainty analysis for *Grassland Remaining Grassland* using the Tier 3 approach and Tier 2 approach were based on the same method described for *Cropland Remaining Cropland*, except that the uncertainty inherent in the structure of the Century model was not addressed. See the Tier 3 approach for mineral soils under the *Cropland Remaining Cropland* section for additional discussion.

Additional Mineral Carbon Stock Change Calculations

A ±50 percent uncertainty was assumed for additional adjustments to the soil C stocks between 1990 and 2005 to account for additional C stock changes associated with amending grassland soils with sewage sludge.

Uncertainties in Organic Soil Carbon Stock Changes

Uncertainty in C emissions from organic soils were estimated using country-specific factors and a Monte Carlo analysis. PDFs for emission factors were derived from a synthesis of 10 studies, and combined with uncertainties in the NRI land use and management data for organic soils in the Monte Carlo analysis. See the Tier 2 section under minerals soils of *Cropland Remaining Cropland* for additional discussion.

QA/QC and Verification

Quality control measures included checking input data, model scripts, and results to ensure data were properly handled through the inventory process. An error was found in these steps and a corrective action was taken. Specifically, the error involved improved estimation of root production in irrigated systems. Root production had been parameterized based on rainfed forages; the parameters were adjusted to approximate C allocation to belowground growth in irrigated lands.

Recalculations Discussion

The specific changes in reporting in the current Inventory for *Grassland Remaining Grassland* are the same as those described in the *Cropland Remaining Cropland* section, except that the uncertainty is not addressed in the current inventory for the random variation associated with Century model estimates at the site scale. The structural uncertainty requires further development before it can be used to address uncertainty inherent in the structure of the Century model for *Grassland Remaining Grassland*. Overall, the recalculations resulted in an average annual increase in emissions of 7.4 Tg CO_2 Eq. (46.2 percent) for soil C stock changes in *Grassland Remaining Grassland* over the period from 1990 through 2004.

Planned Improvements

The empirically-based uncertainty estimator described in the *Cropland Remaining Cropland* section for the Tier 3 approach has not been developed to estimate uncertainties in Century model results for *Grassland Remaining*

Grassland, but this is a planned improvement for the inventory. See Planned Improvements section under *Cropland Remaining Cropland* for additional planned improvements.

7.6. Land Converted to Grassland (IPCC Source Category 5C2)

Land Converted to Grassland includes all areas designated as grassland that had been in another land use in a prior time period according to the USDA NRI land use survey (USDA-NRCS 2000). Consequently, the area of *Land Converted to Grassland* changes through time with land-use change. Lands are retained in this category for 20 years as recommended by the IPCC guidelines (IPCC 2006) unless there is another land use change. Background on agricultural C stock changes is provided in *Cropland Remaining Cropland* and will only be summarized here for *Land Converted to Grassland*. Soils are the largest pool of C in agricultural land, and also have the greatest potential for storage or release of C because biomass and dead organic matter C pools are relatively small and ephemeral compared with soils. IPCC/UNEP/OECD/IEA (1997) recommends reporting changes in soil organic C stocks due to: (1) agricultural land-use and management activities on mineral soils, (2) agricultural land-use and management activities on organic soils, and (3) CO_2 emissions that result from liming of soils with dolomite and limestone. Mineral soil C stock changes and C emissions from organic soils are reported here for *Land Converted to Grassland*, but emissions from liming are reported in *Cropland Remaining Cropland,* because it was not possible to subdivide those estimates by land use and land-use change categories (see the Methodology section below for additional discussion).

Land-use and management of mineral soils in *Land Converted to Grassland* led to an increase in soil C stocks over the entire time series, which was largely caused by annual cropland converted into pasture (see Table 7-26 and Table 7-27). Stock change rates over the time series varied from 14.6 to 16.3 Tg CO_2 Eq./yr (4.0 to 4.5 Tg C). Drainage of organic soils for grazing management led to annual losses of 0.9 Tg CO_2 Eq. in 2005.

Table 7-26: Net Soil C Stock Changes for *Land Converted to Grassland* (Tg CO_2 Eq.)

Soil Type	1990	1995	2000	2001	2002	2003	2004	2005
Mineral Soils[1]	(15.0)	(17.2)	(17.2)	(17.2)	(17.2)	(17.2)	(17.2)	(17.2)
Organic Soils	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Liming of Soils[2]	-	-	-	-	-	-	-	-
Total Net Flux	**(14.6)**	**(16.3)**	**(16.3)**	**(16.3)**	**(16.3)**	**(16.3)**	**(16.3)**	**(16.3)**

Note: Parentheses indicate net sequestration. Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only. Totals may not sum due to independent rounding.
[1] Stock changes due to application of sewage sludge is reported in *Grassland Remaining Grassland*.
[2] Emissions from liming in *Land Converted to Grassland* are reported in *Cropland Remaining Cropland.*

Table 7-27: Net Soil C Stock Changes for *Land Converted to Grassland* (Tg C)

Soil Type	1990	1995	2000	2001	2002	2003	2004	2005
Mineral Soils[1]	(4.1)	(4.7)	(4.7)	(4.7)	(4.7)	(4.7)	(4.7)	(4.7)
Organic Soils	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Liming of Soils[2]	-	-	-	-	-	-	-	
Total Net Flux	**(4.0)**	**(4.5)**	**(4.5)**	**(4.5)**	**(4.5)**	**(4.5)**	**(4.5)**	**(4.5)**

Note: Parentheses indicate net sequestration. Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only. Totals may not sum due to independent rounding.
[1] Stock changes due to application of sewage sludge is reported in *Grassland Remaining Grassland*.
[2] Emissions from liming in *Land Converted to Grassland* are reported in *Cropland Remaining Cropland.*

The spatial variability in annual CO_2 flux associated with C stock changes in mineral soils is displayed in Figure 7-10 and Figure 7-11. Soil C stock increased in most MLRAs for *Land Converted to Grassland*. The largest gains were in the southeast and northwest, and the amount of sequestration increased through the 1990s. The patterns were driven by conversion of annual cropland into continuous pasture. Emissions from organic soils were largest in California, Florida and the upper Midwest, which coincides with largest concentrations of organic soils in the United States that are used for agricultural production.

Figure 7-10: Net Soil C Stock Change for Mineral Soils in *Land Converted to Grassland*, 2005

Figure 7-11: Net Soil C Stock Change for Organic Soils in *Land Converted to Grassland*, 2005

Methodology

The following section includes a brief description of the methodology used to estimate changes in soil C stocks due to agricultural land-use and management activities on mineral soils for *Land Converted to Grassland*.

Soil C stock changes were estimated for *Land Converted to Grassland* according to land-use histories recorded in the USDA NRI survey (USDA-NRCS 2000).[12] Land use and some management information (e.g., legume pastures, crop type, soil attributes, and irrigation) were collected for each NRI point on a 5-year cycle beginning in 1982, and were subdivided into four inventory time periods, 1980-84, 1985-1989, 1990-94 and 1995-2000. NRI points were classified as *Land Converted to Grassland* for an inventory time period (e.g., 1990-1994 and 1995-2000) if the land use was grassland at the end of the respective inventory time period but had been another use in a prior inventory time period. Grassland includes pasture and rangeland used for grass forage production, where the primary use is livestock grazing. Rangeland are typically extensive areas of native grassland that are not intensively managed, while pastures are often seeded grassland, possibly following tree removal, that may or may not be improved with practices such as irrigation and interseeding legumes. Further elaboration on the methodologies and data used to estimate stock changes from mineral and organic soils are provided in the *Cropland Remaining Cropland* section and Annex 3.13.

Mineral Soil Carbon Stock Changes

A Tier 3 model-based approach was used to estimate C stock changes for *Land Converted to Grassland* on mineral soils, with the exception of prior cropland used to produce vegetables, tobacco, perennial/horticultural crops, and rice, in addition to land areas with very gravelly, cobbly or shaley soils (greater than 35 by volume). An IPCC Tier 2 approach was used to estimate C stock changes for portions of the land base for *Land Converted to Grassland* that were not addressed with the Tier 3 approach (Ogle et al. 2003). A Tier 2 approach was also used to estimate additional changes in mineral soil C stocks due to sewage sludge amendments. However, stock changes associated with sewage sludge amendments are reported in the *Grassland Remaining Grassland* section.

Tier 3 Approach

Mineral SOC stocks and stock changes were estimated using the Century biogeochemical model as described for *Grassland Remaining Grassland*. Historical land-use and management patterns were used in the Century simulations as recorded in the NRI survey, with supplemental information on fertilizer use and rates from USDA Economic Research Service Cropping Practices Survey (ERS 1997) and National Agricultural Statistics Service (NASS 1992, 1999, 2004) (see *Grassland Remaining Grassland* Tier 3 methods section for additional information).

Tier 2 Approach

The Tier 2 Approach used for *Land Converted to Grassland* on mineral soils is the same as described for *Cropland Remaining Cropland* (See *Cropland Remaining Cropland* Tier 2 Approach for additional information).

[12] NRI points were classified as agricultural if under grassland or cropland management in 1992 and/or 1997.

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Land Converted to Grassland* were estimated using the Tier 2 method provided in IPCC/UNEP/OECD/IEA (1997) and IPCC (2003), which utilizes U.S.-specific C loss rates (Ogle et al. 2003) rather than default IPCC rates. The final estimates included a measure of uncertainty as determined from a Monte Carlo simulation with 50,000 iterations. Emissions were based on the 1992 and 1997 *Land Converted to Grassland* areas from the *1997 National Resources Inventory* (USDA-NRCS 2000). The annual flux estimated for 1992 was applied to 1990 through 1992, and the annual flux estimated for 1997 was applied to 1993 through 2005.

CO_2 Emissions from Agricultural Liming

Carbon dioxide emissions from degradation of limestone and dolomite applied to *Land Converted to Grassland* are reported in *Cropland Remaining Cropland*, because it was not possible to disaggregate liming application among land use and land-use change categories.

Uncertainty

Uncertainty associated with the *Land Converted to Grassland* category includes the uncertainty associated with changes in mineral soil C stocks. Uncertainty estimates are presented in Table 7-28 for each subsource (i.e., mineral soil C stocks and organic soil C stocks) disaggregated to the level of the inventory methodology employed (i.e., Tier 2 and Tier 3). A combined uncertainty estimate for changes in agricultural soil C stocks occurring within *Land Converted to Grassland* is also included. Uncertainty estimates from each component were combined using the error propagation equation in accordance with IPCC (2006). The combined uncertainty was calculated by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. More details on how the individual uncertainties were developed appear later in this section. The combined uncertainty for soil C stocks in *Land Converted to Grassland* ranged from 13 percent below and 14 percent above the 2005 estimate of 16.3 Tg CO_2 Eq.

Table 7-28: Quantitative Uncertainty Estimates for C Stock Changes occurring within *Land Converted to Grassland* (Tg CO_2 Eq. and Percent)

Source	2005 Stock Change Estimate (Tg CO_2 Eq.)	Uncertainty Range Relative to Stock Change Estimate (Tg CO_2 Eq.)		Uncertainty Range Relative to Stock Change Estimate (%)	
		Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Mineral Soil C Stocks: *Land Converted to Grassland*, Tier 3 Inventory Methodology	(12.2)	(12.5)	(11.9)	-2%	+2%
Mineral Soil C Stocks: *Land Converted to Grassland*, Tier 2 Inventory Methodology	(5.0)	(7.0)	(2.8)	-39%	+43%
Organic Soil C Stocks: *Land Converted to Grassland*, Tier 2 Inventory Methodology	0.9	0.2	1.8	-76%	+104%
Combined Uncertainty for Agricultural Soil Carbon Stocks in *Land Converted to Grassland*	**(16.3)**	**(18.4)**	**(14.0)**	**-13%**	**14%**

Uncertainties in Mineral Soil Carbon Stock Changes

Tier 3 Approach

The uncertainty analysis for *Land Converted to Grassland* using the Tier 3 and Tier 2 approaches were based on the same method described in *Cropland Remaining Cropland*, except that the uncertainty inherent in the structure of the Century model was not addressed.

Uncertainties in Organic Soil Carbon Stock Changes

Annual C emission estimates from drained organic soils in *Land Converted to Grassland* were estimated using the Tier 2 approach, as described in the *Cropland Remaining Cropland* section.

QA/QC and Verification

See the QA/QC and Verification section under *Grassland Remaining Grassland*.

Recalculations Discussion

The specific changes in reporting in the current Inventory for *Land Converted to Grassland* are the same as those described in the *Cropland Remaining Cropland* section, except that the uncertainty is not addressed in the current inventory for the random variation associated with Century model estimates at the site scale. The structural uncertainty requires further development before it can be used to address uncertainty inherent in the structure of the Century model for other uses besides cropland. Overall, the recalculations resulted in an average annual decrease in sinks of 4.3 Tg CO_2 Eq. (21.1 percent) for soil C stock changes in *Land Converted to Grassland* for the time series from 1990 through 2004.

Planned Improvements

The empirically-based uncertainty estimator described in the *Cropland Remaining Cropland* section for the Tier 3 approach has not been developed to estimate uncertainties in Century model results for *Land Converted to Grassland*, but this is a planned improvement for the inventory. See Planned Improvements section under *Cropland Remaining Cropland* for additional planned improvements.

7.7. Settlements Remaining Settlements

Changes in Carbon Stocks in Urban Trees (IPCC Source Category 5E1)

Urban forests constitute a significant portion of the total U.S. tree canopy cover (Dwyer et al. 2000). Urban areas (cities, towns, and villages) are estimated to cover over 4.4 percent of the United States (Nowak et al. 2005). With an average tree canopy cover of 27.1 percent, urban areas account for approximately 3 percent of total tree cover in the continental United States (Nowak et al. 2001). Trees in urban areas of the United States were estimated to account for an average annual net sequestration of 73.0 Tg CO_2 Eq. (19.9 Tg C) over the period from 1990 through 2005. Total sequestration increased by 54 percent between 1990 and 2005 due to increases in urban land area. Data on C storage and urban tree coverage were collected throughout the 1990s, and have been applied to the entire time series in this report. Annual estimates of CO_2 flux were developed based on periodic U.S. Census data on urban area (Table 7-29).

Net C flux from urban trees is proportionately greater on an area basis than that of forests. This trend is primarily the result of different net growth rates in urban areas versus forests—urban trees often grow faster than forest trees because of the relatively open structure of the urban forest (Nowak and Crane 2002). Also, areas in each case are accounted for differently. Because urban areas contain less tree coverage than forest areas, the C storage per hectare of land is in fact smaller for urban areas. However, urban tree reporting occurs on a per unit tree cover basis (tree canopy area), rather than total land area. Urban trees, therefore, appear to have a greater C density than forested areas (Nowak and Crane 2002).

Table 7-29: Net C Flux from Urban Trees (Tg CO_2 Eq. and Tg C)

Year	Tg CO_2 Eq.	Tg C
1990	(57.5)	(15.7)
1995	(67.8)	(18.5)
2000	(78.2)	(21.3)

2001	(80.2)	(21.9)
2002	(82.3)	(22.4)
2003	(84.4)	(23.0)
2004	(86.4)	(23.6)
2005	(88.5)	(24.1)

Note: Parentheses indicate net sequestration.

Methodology

The methodology used by Nowak and Crane (2002) is based on average annual estimates of urban tree growth and decomposition, which were derived from field measurements and data from the scientific literature, urban area estimates from U.S. Census data, and urban tree cover estimates from remote sensing data. This approach is consistent with the default IPCC methodology in IPCC (2003), although sufficient data are not yet available to determine interannual changes in C stocks in the living biomass of urban trees. Annual changes in net C flux from urban trees are based solely on changes in total urban area in the United States.

Nowak and Crane (2002) developed estimates of annual gross C sequestration from tree growth and annual gross C emissions from decomposition for ten U.S. cities: Atlanta, GA; Baltimore, MD; Boston, MA; Chicago, IL; Jersey City, NJ; New York, NY; Oakland, CA; Philadelphia, PA; Sacramento, CA; and Syracuse, NY. The gross C sequestration estimates were derived from field data that were collected in these ten cities during the period from 1989 through 1999, including tree measurements of stem diameter, tree height, crown height, and crown width, and information on location, species, and canopy condition. The field data were converted to annual gross C sequestration rates for each species (or genus), diameter class, and land-use condition (forested, park-like, and open growth) by applying allometric equations, a root-to-shoot ratio, moisture contents, a C content of 50 percent (dry weight basis), an adjustment factor to account for smaller aboveground biomass volumes (given a particular diameter) in urban conditions compared to forests, an adjustment factor to account for tree condition (fair to excellent, poor, critical, dying, or dead), and annual diameter and height growth rates. The annual gross C sequestration rates for each species (or genus), diameter class, and land-use condition were then scaled up to city estimates using tree population information. The field data from the 10 cities, some of which are unpublished, are described in Nowak and Crane (2002) and references cited therein. The allometric equations were taken from the scientific literature (see Nowak 1994, Nowak et al. 2002), and the adjustments to account for smaller volumes in urban conditions were based on information in Nowak (1994). A root-to-shoot ratio of 0.26 was taken from Cairns et al. (1997), and species- or genus-specific moisture contents were taken from various literature sources (see Nowak 1994). Adjustment factors to account for tree condition were based on percent crown dieback (Nowak and Crane 2002). Tree growth rates were also taken from existing literature. Average diameter growth was based on the following sources: estimates for trees in forest stands came from Smith and Shifley (1984); estimates for trees on land uses with a park-like structure came from deVries (1987); and estimates for more open-grown trees came from Nowak (1994). Formulas from Fleming (1988) formed the basis for average height growth calculations.

Annual gross C emission estimates were derived by applying estimates of annual mortality and condition, and assumptions about whether dead trees were removed from the site, to C stock estimates. These values were derived as intermediate steps in the sequestration calculations, and different decomposition rates were applied to dead trees left standing compared with those removed from the site. The annual gross C emission rates for each species (or genus), diameter class, and condition class were then scaled up to city estimates using tree population information. Estimates of annual mortality rates by diameter class and condition class were derived from a study of street-tree mortality (Nowak 1986). Assumptions about whether dead trees would be removed from the site were based on expert judgment of the authors. Decomposition rates were based on literature estimates (Nowak and Crane 2002).

National annual net C sequestration by urban trees was estimated from estimates of gross and net sequestration from seven of the ten cities, and urban area and urban tree cover data for the United States. Annual net C sequestration estimates were derived for seven cities by subtracting the annual gross emission estimates from the annual gross sequestration estimates.[13] The urban areas are based on 1990 and 2000 U.S. Census data. The 1990 U.S. Census defined urban land as "urbanized areas," which included land with a population density greater than 1,000 people per square mile, and adjacent "urban places," which had predefined political boundaries and a population total greater than 2,500. In 2000, the U.S. Census replaced the "urban places" category with a new category of urban land called an "urban cluster," which included areas with more than 500 people per square mile. Urban land area has increased by approximately 36 percent from 1990 to 2000; Nowak et al. (2005) estimate that the changes in the definition of urban land have resulted in approximately 20 percent of the total reported increase in urban land area from 1990 to 2000. Under both 1990 and 2000 definitions, urban encompasses most cities, towns, and villages (i.e., it includes both urban and suburban areas). The gross and net C sequestration values for each city were divided by each city's area of tree cover to determine the average annual sequestration rates per unit of tree area for each city. The median value for gross sequestration (0.30 kg C/m^2-year) was then multiplied by the estimate of national urban tree cover area to estimate national annual gross sequestration. To estimate national annual net sequestration, the estimate of national annual gross sequestration was multiplied by the average of the ratios of net to gross sequestration for those cities that had both estimates (0.70). The urban tree cover estimates for each of the 10 cities and the United States were obtained from Dwyer et al. (2000) and Nowak et al. (2002). The urban area estimates were taken from Nowak et al. (2005).

Table 7-30: Carbon Stocks (Metric Tons C), Annual Carbon Sequestration (Metric Tons C/yr), Tree Cover (Percent), and Annual Carbon Sequestration per Area of Tree Cover (kg C/m^2 cover-yr) for Ten U.S. Cities

City	Carbon Stocks	Gross Annual Sequestration	Net Annual Sequestration	Tree Cover	Gross Annual Sequestration per Area of Tree Cover	Net Annual Sequestration per Area of Tree Cover
New York, NY	1,225,200	38,400	20,800	20.9	0.23	0.12
Atlanta, GA	1,220,200	42,100	32,200	36.7	0.34	0.26
Sacramento, CA	1,107,300	20,200	NA	13.0	0.66	NA
Chicago, IL	854,800	40,100	NA	11.0	0.61	NA
Baltimore, MD	528,700	14,800	10,800	25.2	0.28	0.20
Philadelphia, PA	481,000	14,600	10,700	15.7	0.27	0.20
Boston, MA	289,800	9,500	6,900	22.3	0.30	0.22
Syracuse, NY	148,300	4,700	3,500	24.4	0.30	0.22
Oakland, CA	145,800	NA	NA	21.0	NA	NA
Jersey City, NJ	19,300	800	600	11.5	0.18	0.13

NA = not analyzed.

Uncertainty

Uncertainty associated with changes in C stocks in urban trees includes the uncertainty associated with urban area, percent urban tree coverage, and estimates of gross and net C sequestration for the ten U.S. cities. A 10 percent uncertainty was associated with urban area estimates, based on expert judgment. A 5 percent uncertainty was associated with national urban tree covered area. Uncertainty associated with estimates of gross and net C sequestration for the ten U.S. cities was based on standard error estimates for each of the city-level sequestration estimates as reported in Nowak et al. (2002). These estimates are based on field data collected in ten U.S. cities, and uncertainty in these estimates increases as they are scaled up to the national level.

Additional uncertainty is associated with the biomass equations, conversion factors, and decomposition assumptions used to calculate C sequestration and emission estimates (Nowak et al. 2002). These results also exclude changes in soil C stocks, and there may be some overlap between the urban tree C estimates and the forest tree C estimates. However, both the omission of urban soil C flux and the potential overlap with forest C are believed to be relatively minor (Nowak 2002a). Because these factors are currently inestimable due to data limitations, they are not

[13] Three cities did not have net estimates.

quantified as part of this analysis.

A Monte Carlo (Tier 2) uncertainty analysis was applied to estimate the overall uncertainty of the sequestration estimate. The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 7-31. The net C flux from changes in C stocks in urban trees was estimated to be between -108.5 and -71.3 Tg CO_2 Eq. at a 95 percent confidence level. This indicates a range of 23 percent below and 19 percent above the 2005 flux estimate of -88.5 Tg CO_2 Eq.

Table 7-31: Tier 2 Quantitative Uncertainty Estimates for Net C Flux from Changes in C Stocks in Urban Trees (Tg CO_2 Eq. and Percent)

Source	Gas	2005 Flux Estimate (Tg CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate (Tg CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Changes in C Stocks in Urban Trees	CO_2	(88.5)	(108.5)	(71.3)	-23%	+19%

Note: Parentheses indicate negative values or net sequestration.

QA/QC and Verification

The net C flux resulting from urban trees was calculated using estimates of gross and net C sequestration estimates for urban trees and urban tree coverage area found in literature. The validity of these data for their use in this section of the inventory was evaluated through correspondence established with an author of the papers. Through the correspondence, the methods used to collect the urban tree sequestration and area data were further clarified and the use of these data in the inventory was reviewed and validated (Nowak 2002a).

Recalculations Discussion

In previous inventories, estimates of Tg C had been rounded to 2 signficant figures based on Nowak 2002b. Since a Tier 2 uncertainty analysis was run for this source starting from the current Inventory, this rounding step was removed. This change resulted in a change in emission estimates for 1990 through 2004. On average, estimates of net C flux from urban trees decreased by less than one percent over the period from 1990 to 2004 relative to the previous report.

Planned Improvements

New estimates of C in urban trees based on new satellite and field data are being developed. Once those data become available, they will be incorporated into estimates of net C flux resulting from urban trees.

A consistent representation of the managed land base in the United States is also being developed. A component of this project will involve reconciling the overlap between urban forest and non-urban forest GHG inventories. It is highly likely that urban forest inventories are including areas considered non-urban under the Forest Inventory and Analysis (FIA) program of the USDA Forest Service, resulting in "double-counting" of these land areas in estimates of C stocks and fluxes for the U.S. inventory. One goal of the plan to develop the consistent representation of the United States land base is to eliminate this overlap.

Direct N_2O Fluxes from Settlement Soils (IPCC Source Category 5E1)

Of the synthetic N fertilizers applied to soils in the United States, approximately 10 percent are applied to lawns, golf courses, and other landscaping occurring within settlement areas. Application rates are less than those occurring on cropped soils, and, therefore, account for a smaller proportion of total U.S. soil N_2O emissions per unit area. In addition to synthetic N fertilizers, a portion of surface applied sewage sludge is applied to settlement areas. In 2005, N_2O emissions from this source were 5.8 Tg CO_2 Eq. (19 Gg). There was an overall increase of 13 percent over the period from 1990 through 2005 due to a general increase in the application of synthetic N fertilizers to an expanding settlement area. Interannual variability in these emissions is directly attributable to interannual variability in total synthetic fertilizer consumption and sewage sludge applications in the United States. Emissions from this source are summarized in Table 7-32.

Table 7-32: N_2O Fluxes from Soils in Settlements Remaining Settlements (Tg CO_2 Eq. and Gg)

Year	Tg CO2 Eq.	Gg
1990	5.1	17
1995	5.5	18
2000	5.6	18
2001	5.5	18
2002	5.6	18
2003	5.8	19
2004	6.0	19
2005	5.8	19

Note: These estimates include direct N_2O emissions from N fertilizer additions only. Indirect N_2O emissions from fertilizer additions are reported in the Agriculture chapter. These estimates include emissions from both *Settlements Remaining Settlements* and from *Land Converted to Settlements*.

Methodology

For soils within *Settlements Remaining Settlements,* the IPCC Tier 1 approach was used to estimate soil N_2O emissions from synthetic N fertilizer and sewage sludge additions. Estimates of direct N_2O emissions from soils in settlements were based on the amount of N in synthetic commercial fertilizers applied to settlement soils and the amount of N in sewage sludge applied to non-agricultural land and in surface disposal of sewage sludge.

Nitrogen applications to settlement soils are assumed to be 10 percent of the total synthetic fertilizer used in the United States (Qian 2004). Total synthetic fertilizer applications were derived from fertilizer statistics (TVA 1991, 1992, 1993, 1994; AAPFCO 1995, 1996, 1997, 1998, 1999, 2000b, 2002, 2003, 2004, 2005, 2006) and a recent AAPFCO database (AAPFCO 2000a). Sewage sludge applications were derived from national data on sewage sludge generation, disposition, and nitrogen content (see Annex 3.11 for further detail). The total amount of N resulting from these sources was multiplied by the IPCC default emission factor for applied N (1 percent) to estimate direct N_2O emissions (IPCC 2006). The volatilized and leached/runoff proportions, calculated with the IPCC default volatilization factors (10 or 20 percent, respectively, for synthetic or organic N fertilizers) and leaching/runoff factor for wet areas (30 percent), were included with the total N contributions to indirect emissions, as reported in the N_2O Emissions from Agricultural Soil Management source category of the Agriculture chapter.

Uncertainty

The amount of N_2O emitted from settlements depends not only on N inputs, but also on a large number of variables, including organic C availability, O_2 partial pressure, soil moisture content, pH, temperature, and irrigation/watering practices. The effect of the combined interaction of these variables on N_2O flux is complex and highly uncertain. The IPCC default methodology used here does not incorporate any of these variables and only accounts for variations in national fertilizer N and sewage sludge application rates. All settlement soils are treated equivalently under this methodology. Uncertainties exist in both the fertilizer N and sewage sludge application rates and the emission factors used to derive emission estimates.

The uncertainty in the amounts of sewage sludge applied to non-agricultural lands and used in surface disposal was based on the uncertainty of the following data points, which were used to determine the amounts applied in 2005: (1) N content of sewage sludge; (2) total sludge applied in 2000; (3) wastewater existing flow in 1996 and 2000; and (4) the sewage sludge disposal practice distributions to non-agricultural land application and surface disposal.

The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 7-33. N_2O emissions from soils in *Settlements Remaining Settlements* in 2005 were estimated to be between 2.1 and 10.7 Tg CO_2 Eq. at a 95 percent confidence level. This indicates a range of 49 percent below to 163 percent above the 2005 emission estimate of 5.8 Tg CO_2 Eq.

Table 7-33: Tier 2 Quantitative Uncertainty Estimates of N_2O Emissions from Soils in *Settlements Remaining Settlements* (Tg CO_2 Eq. and Percent)

Source	Gas	2005 Emissions (Tg CO_2 Eq.)	Uncertainty Range Relative to 2005 Emission Estimate (Tg CO_2 Eq.)		(%)	
			Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Settlements Remaining Settlements:						
N_2O Fluxes from Soils	N_2O	5.8	2.1	10.7	-49%	163%

Note: This estimate includes direct N_2O emissions from N fertilizer additions to both *Settlements Remaining Settlements* and from *Land Converted to Settlements*.

Recalculations Discussion

There were several recalculations for the current inventory. The 2003 and 2004 total fertilizer application data were updated from the APPFCO *Commercial Fertilizers* 2003 Report (2004) and 2004 Report (2005). An error in unit conversion used in the sewage sludge calculations was corrected. Changes were made to the data used to calculate the amount of sewage sludge applied from 2001 to 2005, as discussed in Annex 3.11. In the previous inventory, sewage sludge applied as commercial fertilizer was included in total synthetic fertilizer applied, as well as added to the total synthetic fertilizer applied, effectually double counting the amounts of sewage sludge applied to settlements. This error was corrected by not including sewage sludge in total synthetic fertilizer applied. The IPCC default emission factor of 1.25 percent for direct emissions from applied N was updated to 1 percent based on IPCC (2006). Additionally, because the direct emission factor was developed based on total N inputs, the new method has been revised to estimate direct N_2O emissions based on total N input. Previously, a portion of the N inputs were removed from the calculation of direct N_2O emissions, because it was assumed to be lost through volatilization before direct emissions occurred. All of these changes resulted in a 7.6 percent decrease in the emissions estimates for 2004 and an average decrease of about 7.5 percent over the period from 1990 to 2004.

Planned Improvements

The process-based DAYCENT model, which was used to estimate N_2O emissions from cropped soils, could also be used to simulate direct and indirect emissions from settlement soils using state-level settlement area data from the National Resource Inventory.

7.8. Land Converted to Settlements (Source Category 5E2)

Land-use change is constantly occurring, and land under a number of uses undergoes urbanization in the United States each year. However, data on the amount of land converted to settlements is currently lacking. Given the lack of available information relevant to this particular IPCC source category, it is not possible to separate CO_2 or N_2O fluxes on *Land Converted to Settlements* from fluxes on *Settlements Remaining Settlements* at this time.

7.9. Other (IPCC Source Category 5G)

Changes in Yard Trimming and Food Scrap Carbon Stocks in Landfills

In the United States, a significant change in C stocks results from the removal of yard trimmings (i.e., grass clippings, leaves, and branches) and food scraps from settlements to be disposed in landfills. Yard trimmings and food scraps account for a significant portion of the municipal waste stream, and a large fraction of the collected yard trimmings and food scraps are discarded in landfills. C contained in landfilled yard trimmings and food scraps can be stored for very long periods.

C storage is associated with particular land uses. For example, harvested wood products are accounted for under Forest Land Remaining Forest Land because these products are a component of this ecosystem. C stock changes in yard trimmings and food scraps are associated with settlements, but removals do not occur within settlements. Yard trimming and food scrap C storage is therefore reported under "Other."

Both the amount of yard trimmings and food scraps collected annually and the fraction that is landfilled have declined over the last decade. In 1990, nearly 51 million metric tons (wet weight) of yard trimmings and food scraps were generated (i.e., put at the curb for collection or taken to disposal or composting facilities) (EPA 2005). Since then, programs banning or discouraging disposal have led to an increase in backyard composting and the use of mulching mowers, and a consequent 18 percent decrease in the amount of yard trimmings collected. At the same time, a dramatic increase in the number of municipal composting facilities has reduced the proportion of collected yard trimmings that are discarded in landfills—from 72 percent in 1990 to 35 percent in 2003 (the most recent year for which data are available; 2004 and 2005 values are assumed to equal 2003). There is considerably less centralized composting of food scraps; generation has grown by 32 percent since 1990, though the proportion of food scraps discarded in landfills has decreased slightly from 81 percent in 1990 to 78 percent in 2003. Overall, there has been a decrease in the yard trimmings and food scrap landfill disposal rate, which has resulted in a decrease in the rate of landfill C storage to 8.8 Tg CO_2 Eq. in 2005 from 23.0 Tg CO_2 Eq. in 1990 (Table 7-34 and Table 7-35).

Table 7-34: Net Changes in Yard Trimming and Food Scrap Stocks in Landfills (Tg CO_2 Eq.)

Carbon Pool	1990	1995	2000	2001	2002	2003	2004	2005
Yard Trimmings	**(20.2)**	**(11.2)**	**(5.2)**	**(5.4)**	**(5.7)**	**(5.9)**	**(6.0)**	**(6.0)**
Grass	(2.4)	(1.2)	(0.5)	(0.6)	(0.6)	(0.7)	(0.7)	(0.8)
Leaves	(8.2)	(4.6)	(2.1)	(2.1)	(2.2)	(2.3)	(2.3)	(2.3)
Branches	(9.6)	(5.5)	(2.7)	(2.7)	(2.8)	(2.9)	(2.9)	(2.9)
Food Scraps	**(2.8)**	**(1.8)**	**(3.2)**	**(3.2)**	**(3.2)**	**(3.1)**	**(2.9)**	**(2.7)**
Total Net Flux	**(23.0)**	**(13.0)**	**(8.5)**	**(8.6)**	**(8.9)**	**(9.0)**	**(8.9)**	**(8.8)**

Note: Totals may not sum due to independent rounding.

Table 7-35: Net Changes in Yard Trimming and Food Scrap Stocks in Landfills (Tg C)

Carbon Pool	1990	1995	2000	2001	2002	2003	2004	2005
Yard Trimmings	**(5.5)**	**(3.1)**	**(1.4)**	**(1.5)**	**(1.6)**	**(1.6)**	**(1.6)**	**(1.6)**
Grass	(0.6)	(0.3)	(0.1)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)
Leaves	(2.2)	(1.2)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)
Branches	(2.6)	(1.5)	(0.7)	(0.7)	(0.8)	(0.8)	(0.8)	(0.8)
Food Scraps	**(0.8)**	**(0.5)**	**(0.9)**	**(0.9)**	**(0.9)**	**(0.8)**	**(0.8)**	**(0.7)**
Total Net Flux	**(6.3)**	**(3.5)**	**(2.3)**	**(2.3)**	**(2.4)**	**(2.5)**	**(2.4)**	**(2.4)**

Note: Totals may not sum due to independent rounding.

Methodology

As empirical evidence shows, the removal of C from the natural cycling of C between the atmosphere and biogenic materials, which occurs when wastes of biogenic origin are deposited in landfills, sequesters C (Barlaz 1998, 2005). When wastes of sustainable, biogenic origin (such as yard trimming and food scraps) are landfilled and do not completely decompose, the C that remains is effectively removed from the global C cycle. Estimates of net C flux resulting from landfilled yard trimmings and food scraps were developed by estimating the change in landfilled C stocks between inventory years, based on methodologies presented for the Land Use, Land-Use Change and Forestery sector in IPCC (2003) and IPCC (2006). C stock estimates were calculated by determining the mass of landfilled C resulting from yard trimmings or food scraps discarded in a given year; adding the accumulated landfilled C from previous years; and subtracting the portion of C landfilled in previous years that decomposed.

To determine the total landfilled C stocks for a given year, the following were estimated: 1) the composition of the yard trimmings; 2) the mass of yard trimmings and food scraps discarded in landfills; 3) the C storage factor of the landfilled yard trimmings and food scraps adjusted by mass balance; and 4) the rate of decomposition of the degradable C. The composition of yard trimmings was assumed to be 30 percent grass clippings, 40 percent leaves, and 30 percent branches on a wet weight basis (Oshins and Block 2000). The yard trimmings were subdivided, because each component has its own unique adjusted C storage factor and rate of decomposition. The mass of yard trimmings and food scraps disposed of in landfills was estimated by multiplying the quantity of yard trimmings and food scraps discarded by the proportion of discards managed in landfills. Data on discards (i.e., the amount generated minus the amount diverted to centralized composting facilities) for both yard trimmings and food scraps were taken primarily from *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: 2003 Facts and Figures* (EPA 2005), which provides data for 1960, 1970, 1980, 1990, 1995, and 2000 through 2003. To provide data for some of the missing years in the 1990 through 1999 period, two earlier reports were used (*Characterization of Municipal Solid Waste in the United States: 1998 Update* (EPA 1999), and *Municipal Solid Waste in the United States: 2001 Facts and Figures* (EPA 2003)). Remaining years in the time series for which data were not provided were estimated using linear interpolation. Values for 2004 and 2005 are assumed to be equal to values for 2003. The reports do not subdivide discards of individual materials into volumes landfilled and combusted, although they provide an estimate of the proportion of overall wastestream discards managed in landfills and combustors (i.e., ranging from 90 percent and 10 percent respectively in 1980, to 67 percent and 33 percent in 1960).

The amount of C disposed of in landfills each year, starting in 1960, was estimated by converting the discarded landfilled yard trimmings and food scraps from a wet weight to a dry weight basis, and then multiplying by the initial (i.e., pre-decomposition) C content (as a fraction of dry weight). The dry weight of landfilled material was calculated using dry weight to wet weight ratios (Tchobanoglous et al. 1993, cited by Barlaz 1998) and the initial C contents were determined by Barlaz (1998, 2005) (Table 7-36).

The amount of C remaining in the landfill for each subsequent year was tracked based on a simple model of C fate. As demonstrated by Barlaz (1998, 2005), a portion of the initial C resists decomposition and is essentially persistent in the landfill environment; the modeling approach applied here builds on his findings. Barlaz (1998, 2005) conducted a series of experiments designed to measure biodegradation of yard trimmings, food scraps, and other materials, in conditions designed to promote decomposition (i.e., by providing ample moisture and nutrients). After measuring the initial C content, the materials were placed in sealed containers along with a "seed" containing methanogenic microbes from a landfill. Once decomposition was complete, the yard trimmings and food scraps were re-analyzed for C content; the C remaining in the solid sample can be expressed as a proportion of initial C (shown in the row labeled "CS" in Table 7-36).

For purposes of simulating U.S. landfill C flows, the proportion of C stored is assumed to persist in landfills; the remaining portion is assumed to degrade (and results in emissions of CH_4 and CO_2; the CH_4 emissions resulting from decomposition of yard trimmings and food scraps are accounted for in the Waste chapter). The degradable portion of the C is assumed to decay according to first order kinetics. Grass and food scraps are assumed to have a half-life of 5 years; leaves and branches are assumed to have a half-life of 20 years.

For each of the four materials (grass, leaves, branches, food scraps), the stock of C in landfills for any given year is calculated according to the following formula:

$$LFC_{i,t} = \sum_{n} W_{i,n} \times (1 - MC_i) \times ICC_i \times \{[CS_i \times ICC_i] + [(1 - (CS_i \times ICC_i)) \times e^{-k(t-n)}]\}$$

where,

- t = the year for which C stocks are being estimated,
- $LFC_{i,t}$ = the stock of C in landfills in year *t*, for waste *i* (grass, leaves, branches, food scraps)
- $W_{i,n}$ = the mass of waste *i* disposed in landfills in year *n*, in units of wet weight
- n = the year in which the waste was disposed, where $1960 \leq n \leq t$
- MC_i = moisture content of waste *i*,
- CS_i = the proportion of initial C that is stored for waste *i*,

ICC_i = the initial C content of waste *i*,
e = the natural logarithm, and
k = the first order rate constant for waste *i*, which is equal to 0.693 divided by the half-life for decomposition.

For a given year *t*, the total stock of C in landfills ($TLFC_t$) is the sum of stocks across all four materials. The annual flux of C in landfills (F_t) for year *t* is calculated as the change in stock compared to the preceding year:

$$F_t = TLFC_t - TLFC_{t-1}$$

Thus, the C placed in a landfill in year *n* is tracked for each year *t* through the end of the inventory period (2005). For example, disposal of food scraps in 1960 resulted in depositing about 1,140,000 metric tons of C. Of this amount, 16 percent (180,000 metric tons) is persistent; the remaining 84 percent (960,000 metric tons) is degradable. By 1965, half of the degradable portion (480,000 metric tons) decomposes, leaving a total of 660,000 metric tons (the persistent portion, plus the remaining half of the degradable portion).

Continuing the example, by 2005, the total food scraps C originally disposed in 1960 had declined to 181,000 metric tons (i.e., virtually all of the degradable C had decomposed). By summing the C remaining from 1960 with the C remaining from food scraps disposed in subsequent years (1961 through 2005), the total landfill C from food scraps in 2005 was 31.3 million metric tons. This value is then added to the C stock from grass, leaves, and branches to calculate the total landfill C stock in 2005, yielding a value of 220.6 million metric tons (as shown in Table 7-37). In exactly the same way total net flux is calculated for forest C and harvested wood products, the total net flux of landfill C for yard trimmings and food scraps for a given year (Table 7-35) is the difference in the landfill C stock for a given year and the stock in the preceding year. For example, the net change in 2005 shown in Table 7-35 (2.4 Tg C) is equal to the stock in 2005 (220.6 Tg C) minus the stock in 2004 (218.2 Tg C).

When applying the C storage data reported by Barlaz (1998), an adjustment was made to the reported values so that a perfect mass balance on total C could be attained for each of the materials. There are four principal elements in the mass balance:

- Initial C content (ICC, measured),
- C output as methane (CH_4-C, measured),
- C output as CO_2 (CO_2-C, not measured), and
- Residual stored C (CS, measured).

In a simple system where the only C fates are CH_4, CO_2, and C storage, the following equation is used to attain a mass balance:

$$CH_4\text{-C} + CO_2\text{-C} + CS = ICC$$

The experiments by Barlaz and his colleagues (Barlaz 1998, Eleazer et al. 1997) did not measure CO_2 outputs in experiments. However, if the only decomposition is anaerobic, then CH_4-C = CO_2-C.[14] Thus, the system should be defined by:

$$2 \times CH_4\text{-C} + CS = ICC$$

The C outputs (=2 × CH_4-C + CS) were less than 100 percent of the initial C mass for food scraps, leaves, and branches (75, 86, and 90 percent, respectively). For these materials, it was assumed that the unaccounted for C had exited the experiment as CH_4 and CO_2, and no adjustment was made to the measured value of CS.

[14] The molar ratio of CH_4 to CO_2 is 1:1 for carbohydrates (e.g., cellulose, hemicellulose). For proteins as $C_{3.2}H_5ON_{0.86}$, the molar ratio is 1.65 CH_4 per 1.55 CO_2 (Barlaz et al. 1989). Given the predominance of carbohydrates, for all practical purposes, the overall ratio is 1:1.

In the case of grass, the outputs were slightly more (103 percent) than initial C mass. To resolve the mass balance discrepancy, it was assumed that the measurements of initial C content and methane mass were accurate. Thus, the value of CS was calculated as the residual of ICC (initial C content) minus ($2 \times CH_4$-C). This adjustment reduced the C storage value from the 71 percent reported by Barlaz (1998) to 68 percent (as shown in Table 7-36).

Table 7-36: Moisture Content (%), C Storage Factor, Proportion of Initial C Sequestered (%), Initial C Content (%), and Half-Life (years) for Landfilled Yard Trimmings and Food Scraps in Landfills

	Yard Trimmings			Food Scraps
Variable	**Grass**	**Leaves**	**Branches**	
Moisture Content (% H_2O)	70	30	10	70
CS, proportion of initial C stored (%)	68	72	77	16
Initial C Content (%)	45	42	49	51
Half-life (years)	5	20	20	5

Table 7-37: Carbon Stocks in Yard Trimmings and Food Scraps in Landfills (Tg C)

Carbon Pool	1990	1995	2000	2001	2002	2003	2004	2005
Yard Trimmings	**149.8**	**171.5**	**181.4**	**182.9**	**184.4**	**186.0**	**187.7**	**189.3**
Grass	18.2	20.7	21.7	21.8	22.0	22.2	22.4	22.6
Leaves	61.3	70.1	74.1	74.7	75.3	75.9	76.6	77.2
Branches	70.3	80.7	85.6	86.4	87.1	87.9	88.7	89.5
Food Scraps	**20.3**	**23.4**	**27.2**	**28.1**	**28.9**	**29.8**	**30.5**	**31.3**
Total Carbon Stocks	**170.1**	**195.0**	**208.6**	**210.9**	**213.3**	**215.8**	**218.2**	**220.6**

Note: Totals may not sum due to independent rounding.

Uncertainty

The estimation of C storage in landfills is directly related to the following yard trimming and food scrap data and factors: disposal in landfills per year (tons of C), initial C content, moisture content, decomposition rate (half-life), and proportion of C stored. The C storage landfill estimates are also a function of the composition of the yard trimmings (i.e., the proportions of grass, leaves and branches in the yard trimmings mixture). There are uncertainties associated with each of these factors.

A Monte Carlo (Tier 2) uncertainty analysis was then applied to estimate the overall uncertainty of the sequestration estimate. The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 7-38. Total yard trimmings and food scraps CO_2 flux in 2005 was estimated to be between -17.1 and -5.3 Tg CO_2 Eq. at a 95 percent confidence level (or 19 of 20 Monte Carlo stochastic simulations). This indicates a range of 94 percent below to 40 percent above the 2005 flux estimate of -8.8 Tg CO_2 Eq.

Table 7-38: Tier 2 Quantitative Uncertainty Estimates for CO_2 Flux from Yard Trimmings and Food Scraps in Landfills (Tg CO_2 Eq. and Percent)

Source	Gas	2005 Flux Estimate ($Tg\ CO_2$ Eq.)	Uncertainty Range Relative to Flux Estimate[a] ($Tg\ CO_2$ Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Yard Trimmings and Food Scraps	CO_2	(8.8)	(17.1)	(5.3)	-94%	+40%

[a]Range of flux estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
Note: Parentheses indicate negative values or net C sequestration.

QA/QC and Verification

A QA/QC analysis was performed for data gathering and input, documentation, and calculation. The QA/QC check revealed the need to update one of the input values, addressed in the recalculations discussion below.

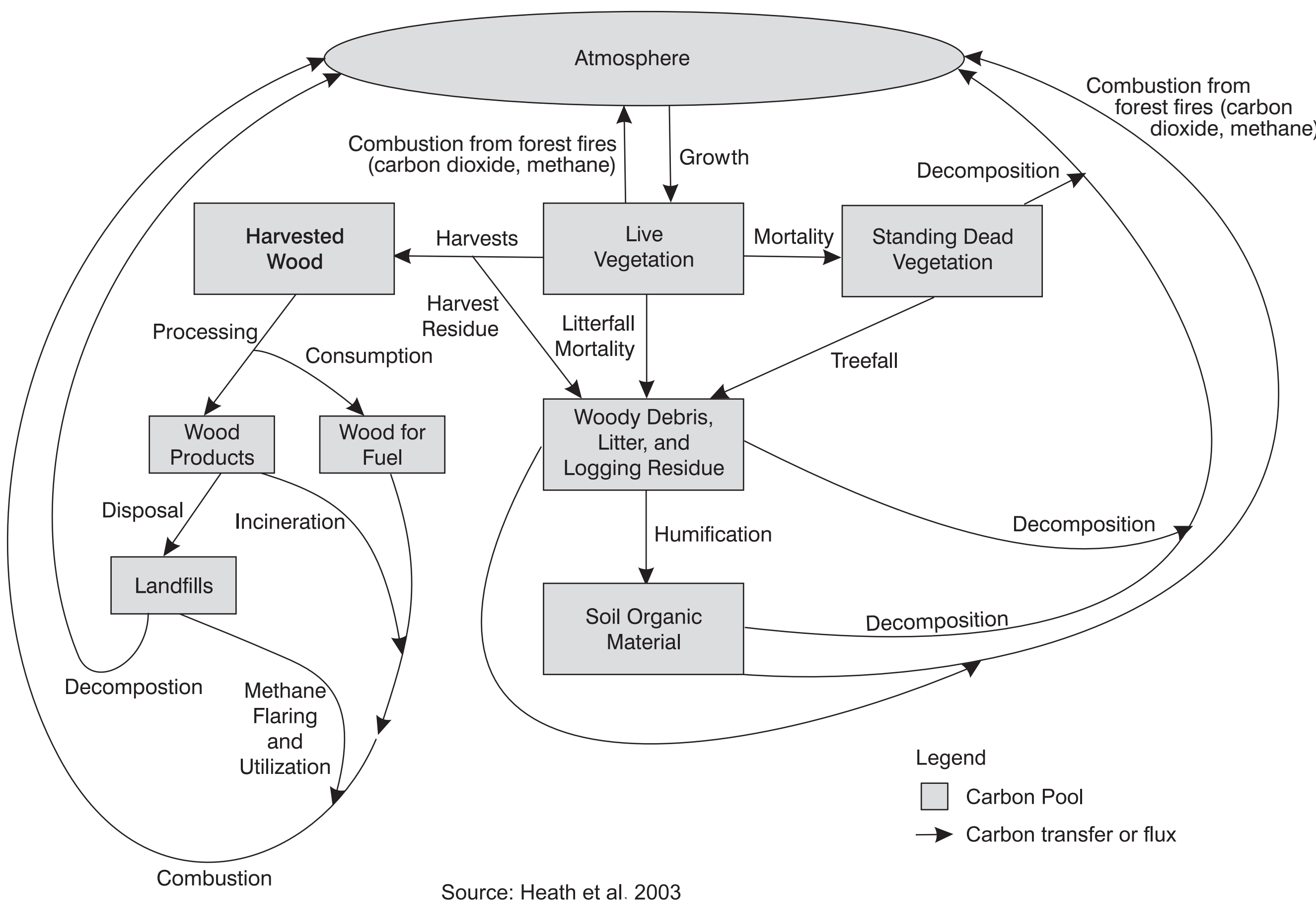
Recalculations Discussion

The only recalculation performed for the current inventory was a correction. The value for the initial C content (ICC) of leaves was updated for the current inventory (41.6 percent) based on updated experimental results provided by Barlaz (2005). Although the previous inventory used an updated value for the carbon stored (CS) for leaves, the initial C content had not been updated (i.e., the earlier experimental value of 49.4 percent was used). This recalculation fixed that problem, and has the effect of reducing the stocks of C from leaves, and also reducing (by about 5 percent) the annual flux for yard trimmings and food scraps.

In the previous inventory, Changes in Yard Trimming and Food Scrap C Stocks in Landfills was included in the *Settlements Remaining Settlements* section of this chapter. However, although C stock changes in yard trimmings and food scraps are associated with settlements, removals do not occur within settlements. Therefore, yard trimming and food scrap C storage is now reported under "Other."

Planned Improvements

Future work may evaluate the potential contribution of inorganic C to landfill sequestration, as well as the consistency between the estimates of C storage described in this chapter and the estimates of landfill CH_4 emissions described in the Waste chapter.



Source: Heath et al. 2003

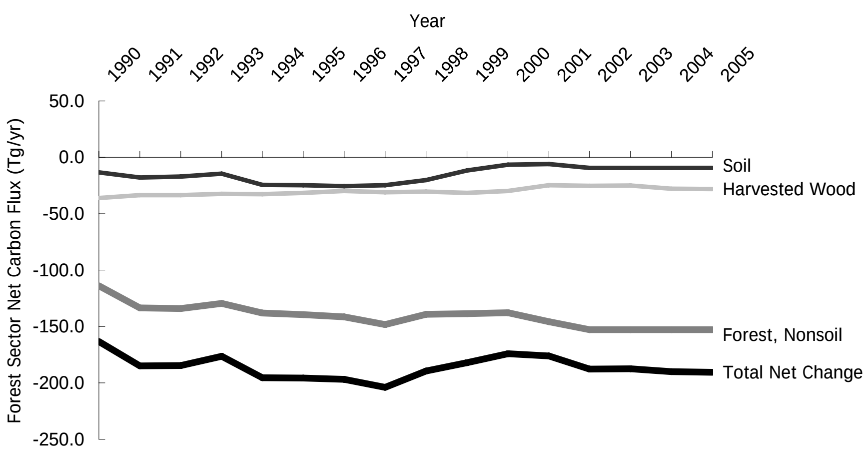
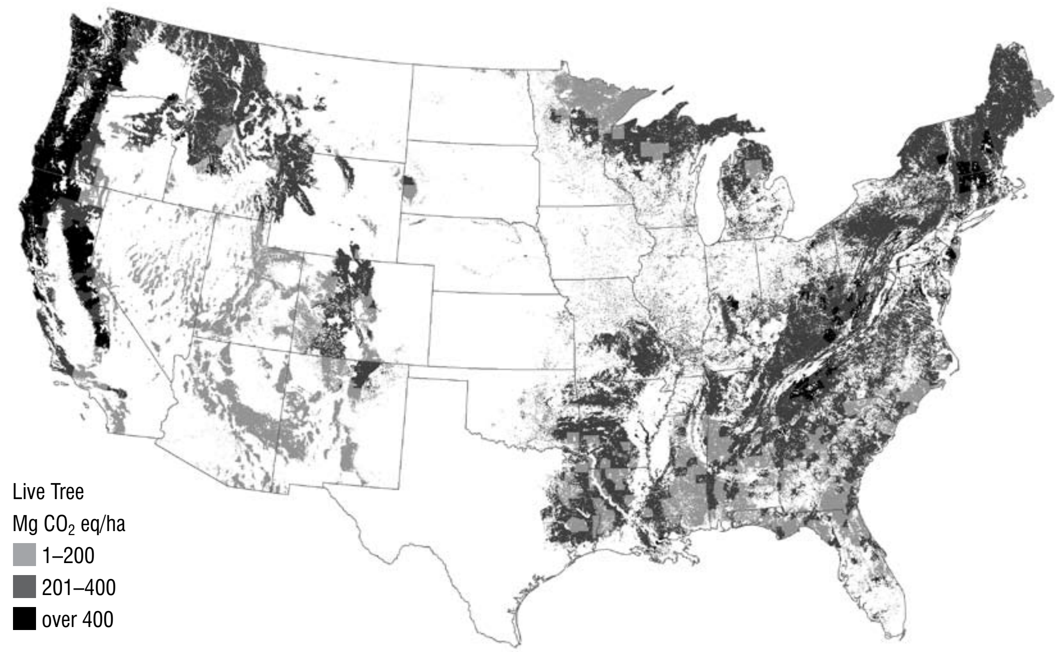


Figure 7-2: Estimates of Net Annual Changes in Carbon Stocks for Major Carbon Pools

Figure 7-3

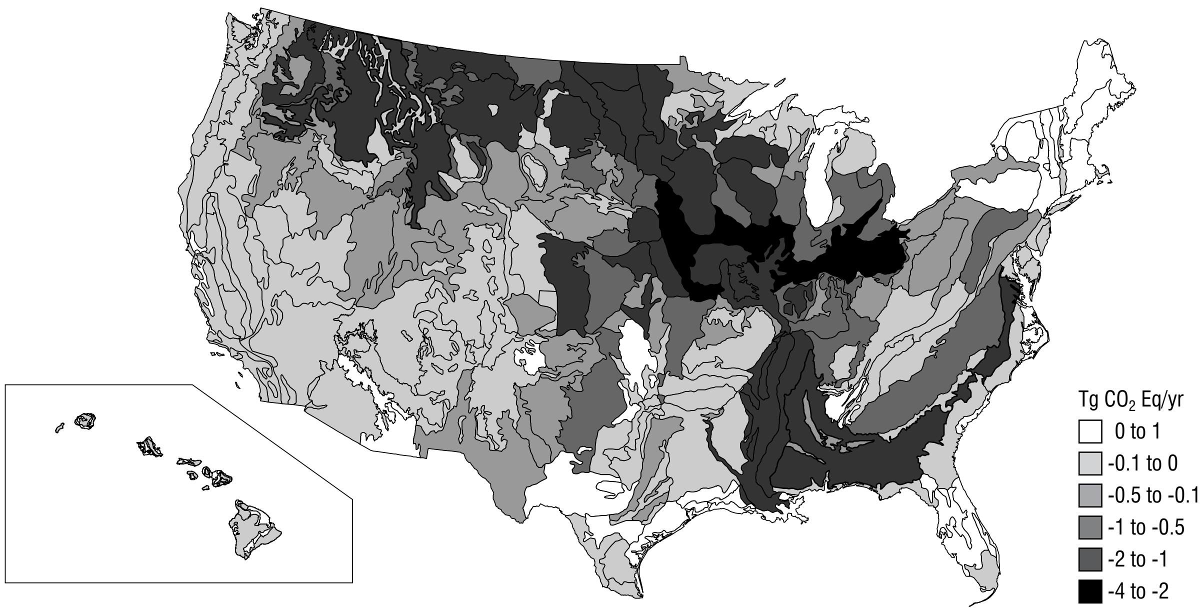
Average Carbon Density in the Forest Tree Pool in the Conterminous U.S., 2006



Note: This graphic shows county-average carbon densities for live trees on forestland, including both above- and belowground biomass. These data are based on the most recent forest inventory survey in each state. (See Table A-3 for the most recent inventory year for each state or substate.)

Figure 7-4

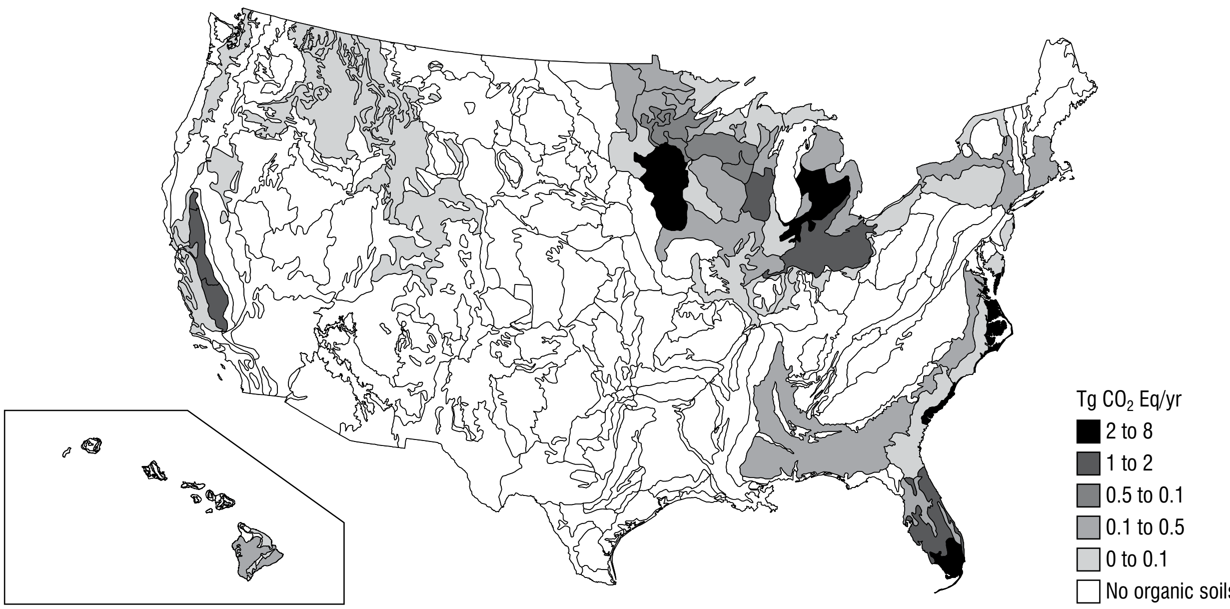
Net Soil C Stock Change for Mineral Soils in *Cropland Remaining Cropland*, 2005



Note: Values greater than zero represent emissions, and values less than zero represent sequestration. Map accounts for fluxes associated with the Tier 2 and 3 Inventory computations. See Methodology for additional details.

Figure 7-5

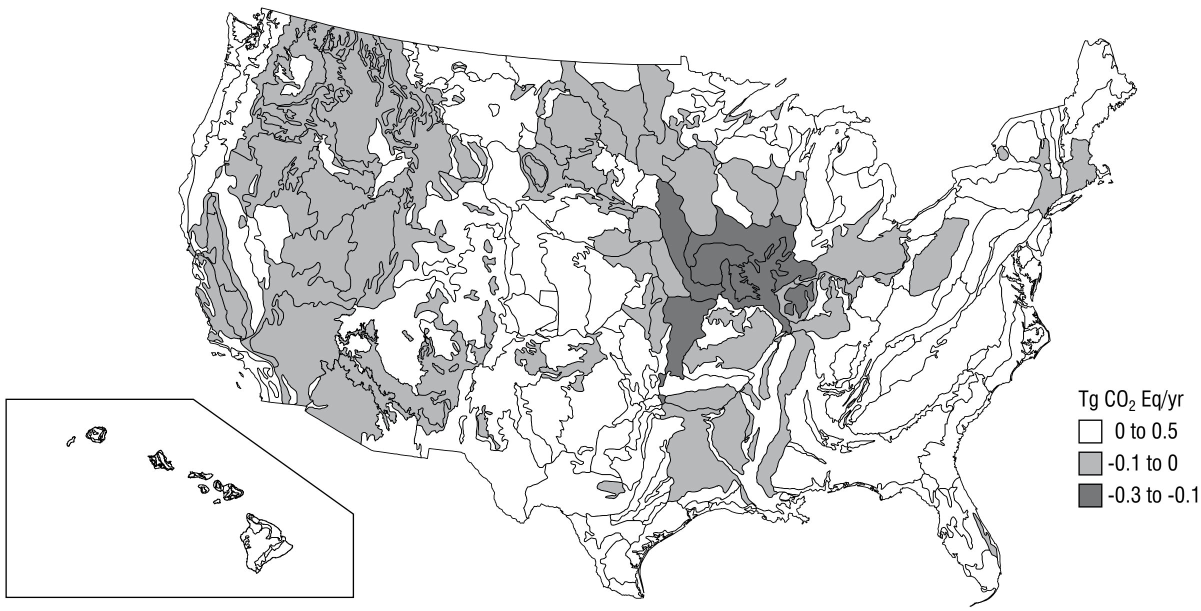
Net Soil C Stock Change for Organic Soils in *Cropland Remaining Cropland*, 2005



Note: Values greater than zero represent emissions.

Figure 7-6

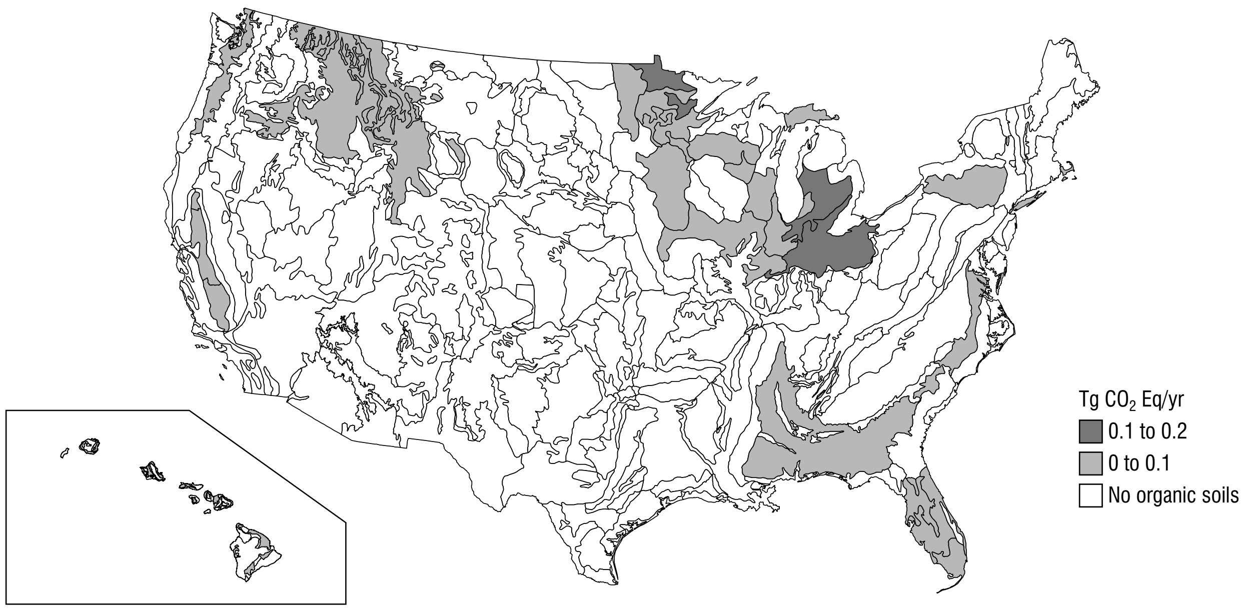
Net Soil C Stock Change for Mineral Soils in *Land Converted to Cropland*, 2005



Note: Values greater than zero represent emissions, and values less than zero represent sequestration. Map accounts for fluxes associated with the Tier 2 and 3 Inventory computations. See Methodology for additional details.

Figure 7-7

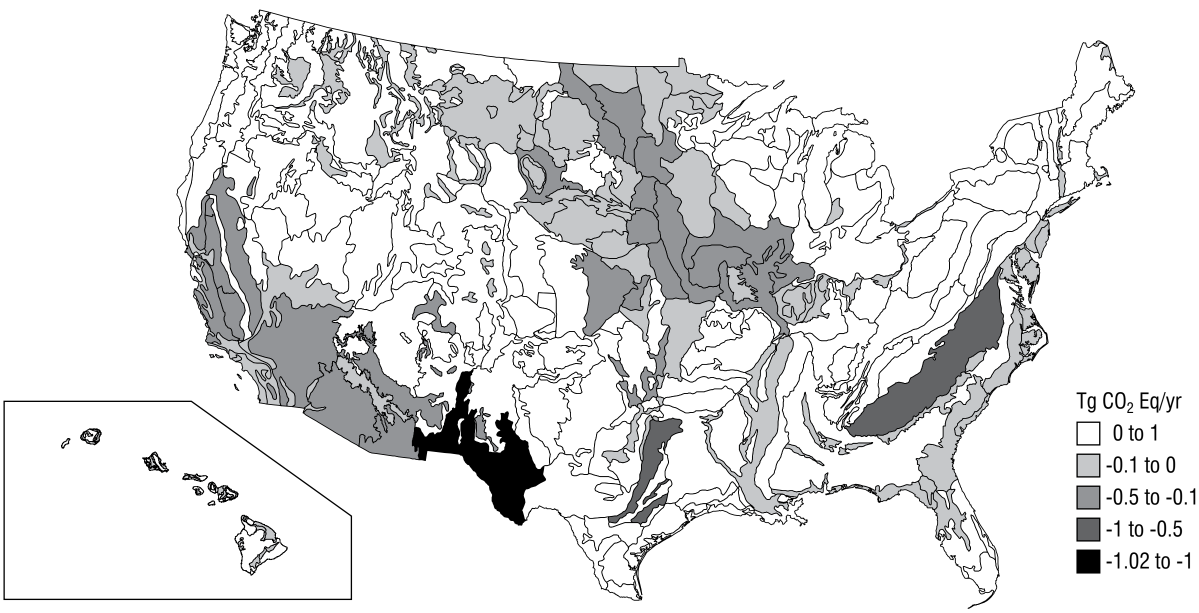
Net Soil C Stock Change for Organic Soils in *Land Converted to Cropland*, 2005



Note: Values greater than zero represent emissions.

Figure 7-8

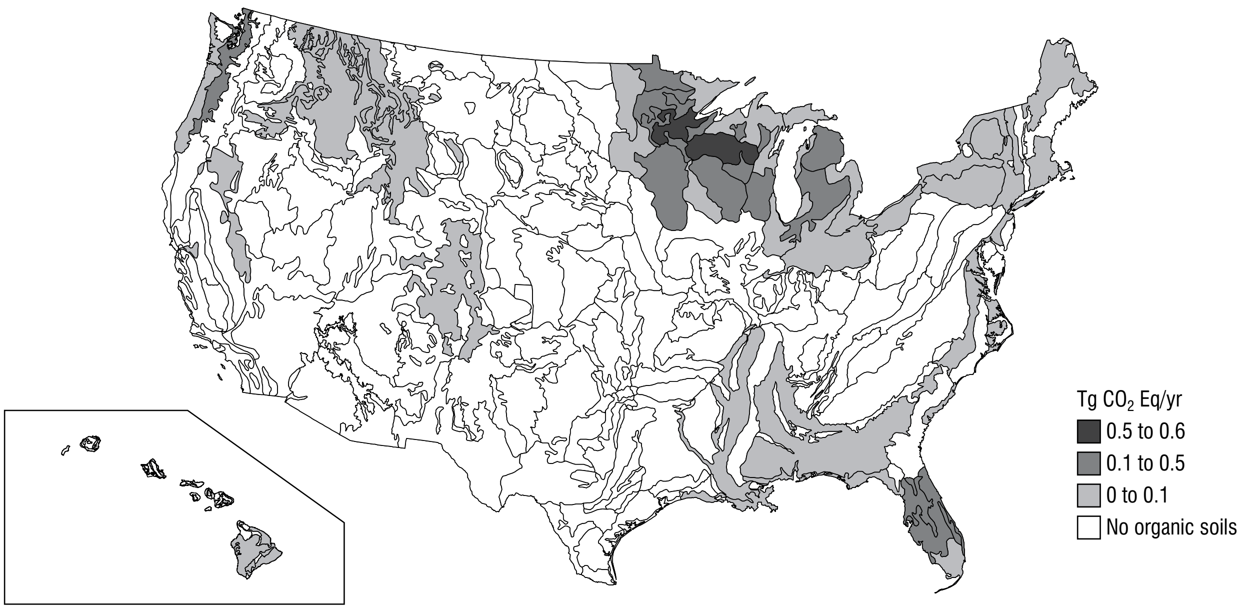
Net Soil C Stock Change for Mineral Soils in *Grassland Remaining Grassland*, 2005



Note: Values greater than zero represent emissions, and values less than zero represent sequestration. Map accounts for fluxes associated with the Tier 2 and 3 Inventory computations. See Methodology for additional details.

Figure 7-9

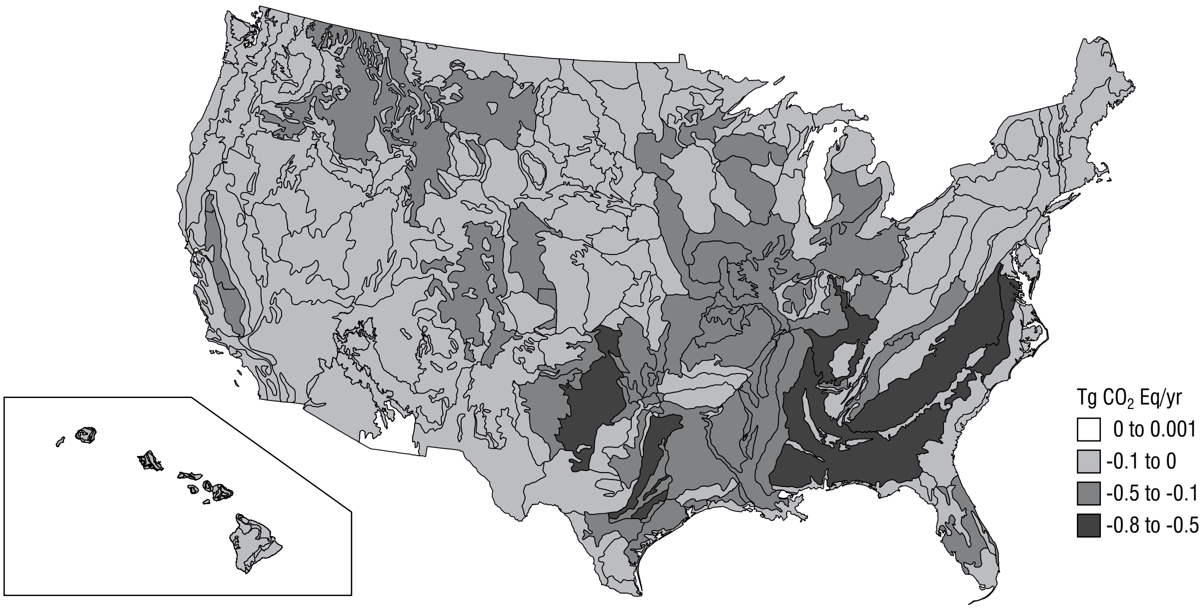
Net Soil C Stock Change for Organic Soils in *Grassland Remaining Grassland*, 2005



Note: Values greater than zero represent emissions.

Figure 7-10

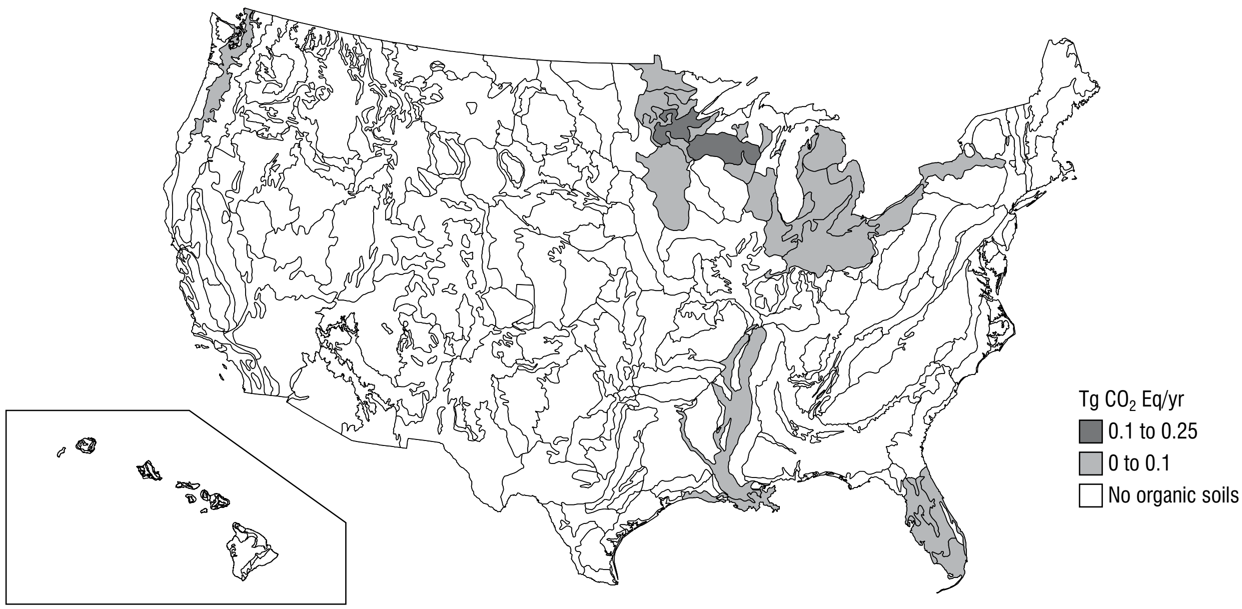
Net Soil C Stock Change for Mineral Soils in *Land Converted to Grassland*, 2005



Note: Values greater than zero represent emissions, and values less than zero represent sequestration. Map accounts for fluxes associated with the Tier 2 and 3 Inventory computations. See Methodology for additional details.

Figure 7-11

Net Soil C Stock Change for Organic Soils in *Land Converted to Grassland*, 2005



Note: Values greater than zero represent emissions.